object-glass or magnifier, for then the whole of the light will be sure to pass through. If it is intended to reduce the intensity of the illumination, then the magnifier, &c. should be placed within the focus according to circumstances, and any portions of the edges of the spectrum may thus be cut off at pleasure.

If the tube (p p p) is unscrewed and removed, another appropriate mounting may be used in place of it, and to this the various object-glasses may be affixed without the body or eye-glasses. The instrument then becomes a solar microscope of superior construction, and the image may be thrown upon the wall of an apartment. the whole apparatus being of course removed from the frame (a), and attached to a window-shutter in the usual way, and the room darkened.

In the case of the engiscope, however, the end of the body (q) is pushed into its receiver at (r, fig. 2), which communicates with a conical tube of brass, having a rectangular prism with its reflecting side silvered, or a plane metal adjusted at its head (s), so as to throw down the image to the bottom of the box or camera, where it is to be received on paper, or on a surface of plaster of Paris duly curved to suit its shape. The camera is constructed with windows (v v), so as to admit two persons to look at a time, and might also be made for three;

amplification, we have only to *select a lens which shall form an image of the sun of the same diameter as the object-glass, and give it the largest angle of aperture possible;* or if a condenser is employed, we may use a lens of long focus and large aperture in the first instance, and condense the image of the sun by a smaller one into the required compass. I should apprehend that an illuminator of twelve inches aperture, and two feet focus, would, as a single glass, give a *maximum* of light with the lower powers used in common solar microscopes; for the higher ones a condenser would be necessary, to enable the whole body of light to clear the small apertures of the object-glasses, and proceed to the picture.

We may draw the following inference from what has been here explained, viz. *that it would be very easy to make a solar instrument on a gigantic scale with an illuminator of enormous actual aperture, which, nevertheless, would have no more light or intrinsic brightness in its image than a much smaller one, scientifically made.*

but I am afraid this would cause the eyes of the observers to be somewhat too far off from the image to see its minutiæ with sufficient exactness; (*w w*) are two pieces of wood carved out to fill the slope of the upper part of the face; one is represented in a plan separately (at 4) in which the aperture (*y*) is seen, and that part of the block which closes round the nose. I have found it necessary to exclude the breath from entering the camera, as it dims the eye-glass of the engiscope, and thus spoils the image.

The sides of the said camera (*u u*) are made to remove at pleasure, to permit the observer to draw the image; some black drapery being hung on in place of the sides, to exclude extraneous light, while the hand is admitted through a cuff made in it. The legs of the camera (*x x*) are made to unscrew at pleasure, others of greater length being used in lieu of them, when it is necessary to elevate the head of the camera to the height of the body of the engiscope when equipped with the opaque box; but blocks of wood with holes in them may of course also be used for the same purpose. The whole of the exterior of the conical brass tube and camera should be well blacked, or lined with black silk velvet. And the totality of the apparatus of the solar engiscope should be placed on a very firm solid table, in an apartment on a ground floor, in a situation where the tremor occasioned by the passing of carriages, &c. cannot be felt.

Fig. III.

Is the opaque apparatus of the solar engiscope, differing but little from that commonly made; when used, it applies to the conical part of the body shown in Fig. 1, by means of the bayonet catch at (*l*), as the transparent apparatus did; (*r*) is a plane mirror governed by the adjusting screw (*s*), to throw up the light of the illuminator to the object (*o*), which is adapted to the focus of the object-glass (*k*), by means of the adjusting

screw (*t m*), which causes the stage which carries the object to move backwards and forwards in a socket, framed in the back of the opaque box. However, I believe it will be found that with such powers as can be used to give images of opaque objects, no adjusting screw will be necessary, for the object may be pushed to-and-fro with the finger with sufficient exactness. The stage is formed by a piece of cork covered with black velvet, to which insects may be fastened by means of the pins used to keep them in their Cabinets; as may also other objects similarly mounted, viz., on corks having pins passed *diagonally* through them: discs also of blackened wood may be made to fit into the stage, in place of the cork one, for receiving insects; and a sort of stage will be found very useful which merely consists of a little round shelf placed rather below the axis of the optical part; on this any thing may be laid for exhibition.

I have supposed the little door of the opaque box to be removed in the drawing, or to be transparent, in order to let the apparatus be seen.

(*p p p*) is merely the tube into which the body of the engiscope (*q*) is inserted as before. It may be removed, and a simple object-glass affixed in an appropriate mounting (at *m*); the instrument then becomes a solar opaque microscope, and is managed as such.

METHOD OF MANAGEMENT—EXHIBITION OF TEST OBJECTS, &c.

It will be remarked, that the necessary directions for managing the instrument are mixed up with the description of its various parts: I think, therefore, little more need to be said, except a few remarks on the exhibition of transparent proof-objects, for little can be done in the way of shewing opaque ones.

The management of the illumination is, perhaps, more easy

in the solar engiscope than in any other; for the light of the sun seems to have the power of bringing out all the lines and markings in tests when thrown perfectly *direct* through the axis, or, where this does not happen to be exactly the case, the natural motion of the sun, if left to itself, soon renders the illumination oblique, and *if the lines happen to be in a proper disposition with respect to it,* brings them out as a matter of course. The line in which the light travels may always be discovered by putting the object out of focus, according to the directions I have given for the management of proof-objects in the Amician catadioptric engiscope; and by turning the slider about, the lines of some of the scales may always be placed at right angles to the direction of the rays For this purpose, however, it will be advisable that the slider should be very short, and have only one hole in it, otherwise there will not be room for it to turn round in the tube (*i*). The condensing lens behind the stage being moved a little on one side, also gives oblique light.

When an object-glass of rather long focus is used, say of two inches, which is a very pleasing magnifier for ordinary objects, the slider-holder should be removed, the object or slide laid flat against the stage, and confined to it by means of its arms; because, in this case, the object-glass may still remain nearly in the focus of the illuminator, which will be at one foot distant from it: if, on the other hand, the body of the engiscope is drawn farther out to adapt itself to the slider-holder, a great loss of light will be the consequence, because the rays from the illuminator will have begun to diverge before they reach the object-glass.

I have frequently been surprised at the great condensation of the solar rays to which the transparent proofs may be exposed, without burning or apparently affecting them in any degree. I have in the winter, when the sun was low, condensed the whole of the light furnished by the illuminator of five inches aperture and one foot focus, by the other behind

the stage of about two inches focus; and *very nearly* in the focus of the latter I have kept the podura for half an hour together, which seemed to resist its action just as cobwebs will do, being, I suppose (like cobwebs) too fine and delicate to arrest a sufficient portion of the calorific rays of the sun to produce combustion. I do not recollect ever burning a transparent proof-object, though I have the slider which held it: but I hardly ever began to exhibit opaque objects without meeting with some accident of the sort;—they can seldom be well shewn without being placed in jeopardy; for it seems to be necessary, in order to get a good picture of these bodies, that *the focus of the illuminator should fall exactly upon them*: it will not answer to place them either within or without the focus, for the purpose of securing them against the danger of combustion; we must, therefore, ascertain, *à priori*, what degree of heat the object we are about to exhibit will be likely to endure, and adapt that of the spectrum to it, by cutting off some of the aperture of the main illuminator, by means of rings of pasteboard placed between it and the mirror. It may sometimes also be advisable to have recourse to the same expedient with transparent bodies, instead of placing them within the focus; and it is, perhaps, the more scientific mode of proceeding of the two, though in the latter case both may be had recourse to. It would, however, be still better to have a spare achromatic illuminator, of the same aperture, but twice the focal length of the other, with an extra joint adapted to lengthen the body, when it was used either on very inflammable opaque objects, or in very hot weather, or in a hot climate, on delicate transparent ones.

With good object glasses of short focus and large angular aperture, of from 1-10th to 1-18th of an inch focus, and about 55° of aperture, a picture of all the markings on the podura may be distinctly exhibited, and likewise the longitudinal lines and their cross striæ on the brassica; *but I have never yet seen a picture of the diagonal lines on the latter*, though I

do not altogether despair of doing so. I have carefully studied the pictures formed by deep achromatic triplet object-glasses acting with Huygherian eye-pieces, and when the said object-glasses were really good, have found their images, *according to my own taste* in such matters, better finished and more perfect than those given by common doublets and triplets of equivalent power. The latter, however, perform very well also, and give the more luminous image of the two; and so will also single magnifiers. I have tried against each other a very fine 1-60th of an inch lens of glass, (equi-convex,) a doublet of 1-70th, and a triplet of 1-50th, and excepting the difference in the size of the image, could not say that I perceived any sensible superiority in either. The engiscope I have mentioned with the object-glass of 1-18th inch focus, though its light was inferior charged with the same powers, *by its mere achromatism instantly effected a great improvement in the picture for the better*; it moreover resolved several of the scales of the podura which the doublets and triplets did not, and shewed the cross striæ on the brassica in a much more decided manner than they did; the said objective, notwithstanding, was far from being a perfect glass, having a considerable quantity of uncorrected aberration of the convex kind, and rather too short a focus to be achromatic.

REFLECTING SOLAR ENGISCOPE.

It is obvious that a reflecting solar engiscope on the Amician principle may very easily be constructed, by applying the body and bar of the catadrioptric instrument, described already in this work, to the top of the camera (fig. 2) in lieu of the conical brass tube, the illuminating apparatus remaining as before, and the aperture in the side of the tube containing the metals being posited precisely where the object-glass of

the refractor is, or, more strictly speaking, where a single object-glass would be, if the instrument was in action as an ordinary solar; I have used an instrument made precisely in this way, only the body and bar were not attached in any way to the illuminating apparatus, but only adjusted so as to coincide well with it. It thus makes a very pleasing instrument; but will only shew the most easy lined objects, from want of power in the objective part, which, as it is well known, cannot be made of less than 3-10ths of an inch focal length, for it requires a *very great depth and power* in an object-glass, or metal, as well as a very considerable degree of perfection, to *render the niceties of proof-objects visible in a picture formed of them;* moreover, the reflecting engiscope is well known to be much darker than an achromatic instrument of equivalent power and angular aperture; and there is another unfortunate circumstance attached to it (the reflector) when used as a solar engiscope, viz. *the hole in the side of the tube, which is always much smaller than the object metal*; for in order that the illumination should be a maximum, *the spectrum of the illuminating lens must fall upon this hole, and clear it,* as it does the object-glass in the refractors, which are of course of much larger diameter than the said hole, and therefore can admit a much greater quantity of light.

Opaque objects can hardly be depicted at all by the reflector; and as the metals of long focus are usually made of small angles of aperture, merely to create space between the sides of their containing tubes, for the purpose of illuminating opaque bodies, it would be advisable if a regular reflecting engiscope was tried to make them with as large *angles* of aperture as possible, because they can, in the said instrument, only operate on diaphonous subjects: thus, that of two inches focus should have an inch at least of aperture, instead of half an inch; that of an inch focus, half an inch, and so on, in order to gain as much light as possible. After all that could

be done, however, I am afraid a refractor would be sure to beat it hollow*; therefore I shall take my leave of the subject, as I cannot conscientiously recommend such an instrument.

OXY-HYDROGEN ENGISCOPES.

These instruments are constructed by applying the optical part of an achromatic engiscope, with the camera already described, in lieu of the magnifiers and screen used with the ordinary oxy-hydrogen microscope; but retaining the illuminating and other apparatus belonging to the latter instrument: in short, the construction must be so obvious to the artist, that I conceive it perfectly superfluous to say any thing farther on the subject. Whatever advantages are possessed by solar engiscopes over solar microscopes, will, in like manner, be retained by oxy-hydrogen engiscopes, or oxy-hydrogen microscopes; *but there is a milkiness, or want of serenity and clearness,* in the light produced by the action of the oxy-hydrogen blowpipe on lime, which renders it very inferior, in the exhibition of the superior order of tests, to that of the sun. How, indeed, can we expect it should be otherwise? I am afraid this would still be the case if the light of the lime could be rendered as intense and brilliant as that of the great luminary at his proper distance from us.

Much has been said about the superiority of the hydro-oxy instruments, in enabling us to dispense with the uncertain sun of our northern climates, and about solar microscopes requiring our confinement during the finest part of the day, &c.;

* A friend of mine, who was perfectly qualified to make such experiments, assured me that he had constructed a solar microscope, with metals on the Amician principle, used *without a body or eye-glasses*, and exhibiting an image in the usual way on the wall of an apartment, and found that it exhibited a variety of test objects in a highly satisfactory manner. I have myself never tried the metals in this way.

but we must not forget that in *warm climates* the light of the sun is nearly certain for months together; and so fiercely is shed "the intolerable day," that we are kept at home under penalty of a knock on the head from this mighty body. Under these circumstances, more especially where every puddle swarms with life, and the whole atmosphere with the most brilliant and curious insects, I humbly think a solar microscope or engiscope, managed by a couple of slaves, who might easily be trained to exhibit it, would have as many charms as a siesta; unless, indeed, the heat should prove so oppressive as to incapacitate us for all rational amusement, and compel us to sleep, whether we will or not. People cannot have their cake, and eat it too; and if they will sleep by day, they must lay awake at night; I therefore recommend the inhabitants of warm regions, whether black, brown, whitey brown, toad-coloured, red, yellow, or white, to betake themselves to these instruments, and try their effect in killing time during the heat of the day, in conjunction, of course, with cards, hookahs, dancing girls, &c. &c., and never to forget their obligations to me for suggesting to them a new species of pleasure.

C. R. G.

CHAPTER V.

ON TRYING

MICROSCOPES AND ENGISCOPES

AGAINST EACH OTHER;

WITH RULES FOR ASCERTAINING THEIR COMPARATIVE MERITS.

TRYING instruments against each other may be thought a mighty simple affair, and that very little can be said or written with propriety on such a subject. As much may be asserted of running horses against each other: nevertheless, horse-racing has its rules and regulations, established by the joint consent of the sporting world, many of whose ordinances may appear at first sight not a little unjust and absurd. Thus, that two horses matched against each other should not carry equal weights on account of a difference in their age, and that such weight shall be determined by a scale nearly or altogether arbitrary; that a horse shall be considered beat because his opponent happened to come in first by *some small fraction of the length of his head;* or that the most trifling loss of weight in the rider, such as that of his whip, shall cause the horse to lose, though he was to distance his adversary by a hundred yards at the goal, and the like, certainly must be considered very vexatious laws; and though they are as fair for one person as another, it may be truly said they are fair for nobody. However, when such consequences attend the loss or winning of a race as the loss of perhaps twenty or thirty

thousand pounds, and the utter ruin of one man to the making of the fortune of the other, it is evidently necessary that the most minute circumstances should be taken into consideration, and that every possible contingency should be determined in some way or other, so as to place the matter beyond controversy or appeal, or every race-course would present nothing but a scene of angry contention, and of quarrels which only an appeal to arms would settle.

Now let us suppose that a couple of microscopists were to pit their microscopes or engiscopes against each other, to shew some particular proof object; and in order to increase the interest of the trial, should bet sums of money on the event; how, and in what manner, are we to determine which instrument shews the said object best, and which of the parties is to lose his money on the occasion? We cannot for a moment suppose that either of the parties will have such excessive candour and complacency as to give up the point when it should be given up: no, every man is almost sure to make an idol of *his own* instrument, be it what it may. If the case resolves itself into *a matter of opinion*, one man's is at least as good as another's; and an ounce of a man's own wisdom is always worth a tun of his neighbours. Is it not most notorious that all *savans*, inventors, and projectors, have, time immemorial, regularly puffed their own productions, and decried every thing else with scarcely a grain of candour? The most trifling mote in the works of others they can see, and expose and magnify; but they cannot and will not see the beams in their own.

Under all these circumstances I think we must begin by laying it down as a rule that no man's judgment is worth a straw, relative to *his own instrument,* even in a case where there is no money to be lost or won by it. In the case proposed above it would be necessary to appoint two indifferent persons as judges; and if they cannot agree, to refer the matter to a third, as umpire, whose judgment should be final,

and without appeal. If it should be asked, of what description should such persons be—should they be profound opticians or microscopists?—I should answer, that any individuals whose sight is perfect are competent to the task; the more so, perhaps, if they never looked into a microscope in their lives, for then they are likely to be without prejudices of any kind. I was myself, when I first began to reform microscopes, very much in the habit of taking the opinion of *an actress* on them; and her decisions were anything but agreeable to me, though I believe they were perfectly correct. Whatever objections there may be to the owners or inventors of particular instruments being allowed to have any voice in determining their specific merits, they are the most proper persons in the world to have the management of them, as they will be sure to display their powers and properties to the greatest advantage, and make them so put forth their whole mettle as certainly as a man will who rides his own horse, and has betted money in his favour on the race-course: therefore it is not necessary for the judges to understand a tittle of the method of managing microscopes or engiscopes, all of which is to be left to the commanders of them: the said judges have nothing to do but to look at the object when duly prepared for their scrutiny.

Having pitched upon judges, it remains for us to ascertain by what laws they shall be governed in their decisions; for it is impossible to give a sound judgment in any case without reference to certain principles; even a common game at cards cannot be lost or won but according to certain rules.

I shall lay down what I consider the laws by which microscopes and engiscopes ought to be judged beaten or victorious; they who do not relish them can establish others, which they may consider more equitable; for laws there must be, of some kind or other, before we can proceed a step in our decisions.

SECTION I.

CODE.

Art. 1.—That instrument is the best which shews the different details of objects most decidedly, and with the greatest clearness and perspicuity*; no matter of what nature or kind, or whether it is chromatic or achromatic, planatic or aplanatic, in or out of adjustment, or whether its lenses are well or ill

* The capability of counting accurately the number of any particular traits or objects, developed both in telescopes and microscopes, has been adduced as decided evidence of the goodness of these instruments, and their power of shewing things in a *decided and forcible manner*. I know not exactly how the truth may be; of this I am certain, that I have seen objects as I should say with the very *intensiva of distinctness*, and yet I am quite confident I could not have counted them truly: perhaps I have not acquired the habit of doing so, or may have some natural incapacity on the subject; for I have frequently found myself unable to count aright the number of sheep in a meadow, when not amounting to more than threescore. I have heard graziers assert that considerable practice is necessary in order to be able to count sheep and herds of cattle accurately.

With respect to lined objects, I have, in the "Microscopic Cabinet," p. 179, given it as my opinion, that they are seen to the greatest advantage, and in the most perfect style, when the spaces between the lines are clear, and the lines themselves dark and strong, as if drawn with a pen and ink on white paper. When scales and feathers are exhibited as opaque bodies—for example, a scale of the diamond beetle—with a high power, the lenses should appear as furrows, or with distinct ridges, dark one side and light on the other, as a ploughed field seen when the sun is low in the horizon, and its beams play across the furrows. Where several systems of faint lines cross each other *in an irregular manner*, the result will be an appearance similar to the watering of silks and moreens. This may be verified by applying two wire sieves, or two pieces of worsted gauze, to each other, and holding them up to the light. The markings on some scales of the podura seem to be of this description; others seem mere points, arranged so as at first sight to give the appearance of a system of lines, or of two crossing each other. The studs on the skin of a boiled pullet, seen as opaque bodies, removed to some distance from the eye, are not an inapt illustration of this sort of optical deception; those of the feathers near the pinions, in particular.

There is certainly a very great difference in the degree of facility with which different specimens of the podura may be resolved into lines, as

worked, or polished, or centered. If a microscope made out of the lens in the eye of a stinking whiting *would shew me something which I could not see with any other**, I should say it was the best, and had beaten every thing else out of the field.

Art. 2.—*The same identical object* must be applied to each microscope and engiscope, tried against each other: supposing the objects to be the scales of insects, a drawing must be made of the configuration of them, that we may be able always to pitch upon one particular specimen.

Art. 3.—Cæteris paribus, I should say, *that instrument which will shew an object perfectly with the lowest power is the best:* thus if one instrument, A, shews an object distinctly and satisfactorily with a power of 200, while another, B, will shew all its minutiæ equally well, though *on a smaller scale*, with 100, I should say that B was the best: in this case I suppose that when the power of each is made equal to 100, the performance of both is not equal, but that B has the advantage. But if the power of each was raised to 200, and then A had the advantage, I should still say that B was the best. I have often insisted on this point in my writings, and assigned what I consider sufficient reasons for my assertions.

well as in the strength and plainness of their markings. A curious phenomenon sometimes presents itself in some choice pet scales, having straight lines from end to end, and two systems of oblique lines also, both apparently grooved in a decided manner, as is the case with many I have seen; viz. one of these systems may be seen by looking *directly*, and the other, *without any alteration in the illumination*, by looking *obliquely* into the instrument. The same circumstance occurs with some other tests.

* There is a very ordinary object, which I can never see with any instrument, which certainly we should expect to be visible by mere magnifying power, with the common microscope;—I allude to the edge of a very sharp razor, presented to the axis in a line bisecting the thickness of the back, so that the thickness of the said edge, or its apex, should be truly shewn and measured, as it may be in a dull case-knife. I suspect the edge of a very sharp razor is the nearest approach to a *mathematical line* with which we are acquainted; it seems to resist magnifying power altogether, or at least such as we can apply to it.

Art. 4.—If two instruments, C and D, shew the lines and markings on an object equally well; but C shews the edge of the scale or feather with the same adjustment of the focus which serves best to bring out the lines, so that the outline and the lines are simultaneously visible, and D does not; then C is the best.

Art. 5.—If one instrument shews the lines on any particular test as if composed of an aggregation of dots or globules; or exhibits them broken, interrupted, and ragged, while another shews them clearly made out, as veritable lines or stripes drawn with a pen and ink; the latter is the best. In the first paper I wrote on test objects, I have given as many as five degrees of illusive or false vision produced in the appearance of the feather of the *Morpho Meneläus*, by viewing them with an object-glass deficient in defining and penetrating power.—*Vide* Quarterly Journal, Vol. xxii. p. 265*.

Art. 6.—If two instruments shew certain lined objects *as transparent bodies* equally well in all respects, but one will shew them more or less evidently *as opaque objects* also, while the other will not, then it has clearly the advantage over the other.

N.B.—One of the best methods of exhibiting scales as opaque bodies is to take away the disc of talc next the eye, replacing the ring; and then to attach a black wafer, or a bit of black paper, to the reverse of the remaining piece of talc, to which some of the scales will generally adhere. In this case I have supposed the scales under consideration to have been mounted in the ordinary way, in slides or circlets, as transparent bodies; and that we wish to be sure of seeing some of the same scales we have seen as transparent bodies, as opaque ones also. If the upper piece of talc is allowed to remain, it will prove a considerable detriment to vision; but still it will be as unfavourable to one instrument as to another.

* See also "Illustrations of the Effects of Aperture," &c. &c. in this work.

Art. 7.—If two instruments should prove equal in all other respects, but one is achromatic and the other not, that which is achromatic has of course the advantage, as it will shew the objects perfectly free from false colouring.

Art. 8.—If two instruments seem to shew transparent bodies equally well, but one of them, when tried upon opaque ones, has a slight fog of the diffused kind over its whole field, or a penumbra or nebulosity encircling numerous points, to a certain distance from them, while the other is free from this illusion, that which shews the opaque objects best is the winner, for opaque objects are still more severe tests than transparent ones.

Art. 9.—Whenever one instrument happens to shew some marking or feature in an object not visible in another, and the owner of the latter attempts to get rid of this, by asserting that it is an illusion produced by some defect of his antagonist's instrument, let him be made to *prove* his assertion to the satisfaction of the judges, or the umpire; and if he cannot do so, let him be turned adrift as a scamp and blacklegs. Let us suppose, for example, that the trial was the wheel animalcule *(vorticella rotatoria)*; and that in the instrument said to exhibit an illusion two points were visible near the head of the animal, when in its grub form, with the wheels withdrawn, (supposed by some naturalists to be the eyes of the animalcule) I should say that the *illusion* here was in the instrument, which *did not shew them*; for a false evidence may be given by suppressing facts, as well as by coining false ones.

There are several minor points which might be insisted upon; such as that instruments which have a strong natural light, combined with a large field of view, free from distortion, and equally good all over, have the advantage over such as cannot pretend to these properties; but as such instruments no not seem to possess any absolute power of *shewing anything more or better* than others, I shall lay small stress on these properties.

When we wish to ascertain which instrument is most perfect in point of *figure*, *achromatism*, or *adjustment*, &c. I have laid down abundant rules for this purpose in Chap. XIX. of the "Microscopic Cabinet," and shall merely therefore remark, that if we wish to ascertain which instrument is constructed on the *best principle*, and what kind of microscopes or engiscopes are made on the most effective plan, in this case the instruments to be tried against each other should have their object-glasses or metals of exactly the same angular aperture and focus; their bodies also should be of the same length, and their eye-glasses of the same nature, description, and magnifying power. When doublets, or triplets, or single magnifiers, are tried against each other, their power and angular aperture must also be scrupulously equalized; or if they are tried against engiscopes, their power and aperture must also be made equal to theirs.

In my paper in the "Microscopic Cabinet," page 202, line 22, nearly a whole paragraph is wanting; which unfortunately changes the sense of the context, and makes it read very ill. This being part and parcel of my present subject, I shall here introduce, as well as I can, from memory, not having the manuscript by me.

"It must however be recollected that single and compound magnifiers, the diameters of which exceed that of the iris of the eye, for the time being, cannot have their aberrations, either chromatic or spherical, estimated in the manner detailed above; because the said iris, or moveable curtain, of the eye, cuts off their aperture to its own standard, so that only *a certain central portion of them*, equal to it in diameter, can be tried. When their foci are too short to be tried on opaque objects, their defects and aberrations may be looked into by viewing the penumbra of transparent objects put out of focus; or rather the penumbra of some body which is not transparent by intercepted light proceeding from behind it." Then should follow the concluding sentence of the paragraph.

Since writing the paper I have alluded to, in the "Cabinet," I have discovered an object which will be found very useful as a test of aberration, when the focus of an object-glass, or of a single or compound magnifier, is too short to allow us to see a globule of quicksilver with it as an opaque body.

Stick two pieces of talc together with a little Canada balsam, in such a manner as to include some small globules of air between the plates; this will be very easily effected: when these are viewed by intercepted light, they appear as *very small discs perfectly black, having a luminous point in the centre*, which has almost the appearance of an artificial star, only not so bright: by putting this within and without the focus (always taking care that the illumination, which should be day-light, is reflected by a plane mirror, is thrown *directly through* it, otherwise the luminous spot will not be centrical), the state of an object-glass or magnifier, as to chromatic and spherical aberration, adjustment, and centricity, &c. can be as well looked into as by a globule of quicksilver, and the pretensions of different constructions scrutinized and brought to the grind-stone.

Another object of a similar nature can be produced by mixing together some oil and water in an aquatic box, and agitating the two fluids until the water is dispersed into very minute globules, surrounded by the oil; in this state they closely resemble the air bubbles, surrounded by the balsam.

SECTION II.

It will probably be expected by the public that I shall now take upon me the disagreeable and invidious task of favouring the world with my own particular notions of the comparative merits of the different sorts of microscopes and engiscopes; an

office which I am afraid I shall execute to the satisfaction of no one human being, while I shall be certain of putting the noses of a great many completely out of joint: I would as soon undertake to give a comparative estimate of the beauties and perfections of a dozen different women, to the satisfaction of the ladies themselves and their lovers. I really think I have gone far enough in laying down a code of laws on the subject, which others may put in execution, (at least if they like.) If, however, I may be permitted to proceed to judgment, according to my own code, I will endeavour to do so: I will not hazard any mere opinions, if I can help it, but merely *state facts, and draw (if possible) legitimate inferences from them*; and if they should happen to be at variance with statements heretofore published by me, I request my reader to consider those now to be given by me as my *most mature conclusions, revised and corrected,* with the whole attention of which my mind is capable, according to the most recent improvements in the different instruments. Though, as I have already asserted, there is no microscopist living who may be expected to give a perfect and absolutely unbiassed criticism on the matter in question, yet I may be as well qualified for the task as most others; for I have been principally concerned from the very beginning in carrying into effect the various reforms in the structure of instruments which have made them what they now are, and may therefore regard them all with equal favour. If I have never interested myself much about compound magnifiers, it was because I conceived that a very great man had taken up the subject before me, and exhausted it, leaving opticians nothing to do in the branch, but to carry his theories and combinations into effect to this best of their ability.

As the subject is one on which much stress is laid by many, I shall here take into consideration the comparative illuminative power, or intrinsic brightness, or light, of various instruments; though I think it will be found in the sequel not to merit much attention, as far as microscopes are concerned.

If we take a piece of any well-polished plane glass, placing a piece of black velvet, or some other dark substance, behind it, to prevent the image from being confused with the rays which it refracts from surrounding objects—or, what is still better, a piece of black glass, having the same reflecting power as the white, and view the picture which it forms of a landscape, or any thing else reflected, as nearly as possible at *right angles* by it—we shall be surprised at the quantity of light arrested by a single surface only, for in the image may be distinctly recognized every object seen in the landscape by the eye, together with its colour; only every thing is a vast deal darker than in nature, the difference being apparently about as great as the light of a twilight evening is to that of meridian day. Now, when we reflect that eyery polished glass surface reflects an equal quantity of light, we may wonder how we see objects at all in an instrument composed of many glasses, and may be very much inclined to think that the fewer glasses we see through, the more perfect must be our vision; that, in short, single lenses must inevitably be the best instruments after all; and such was the opinion of Leeuwenhoek and all the early microscopists. Lenses formed of gem, especially diamond, must be much darker than glass ones, from the greater reflective power of such substances, which defect, however, ought (if there be any truth in analysis) to be much more than compensated for by their high refractive and low dispersive power. Jewelled simple microscopes, then, (*à priori* at least), should seem, upon the whole, to stand upon the top of the scale; but as we here only consider *illuminative power*, they certainly occupy only the second rank, or, if coloured, as is the case with many of them (sapphire and garnets, for example), a still lower one. Doublets must of course arrest twice as much, and triplets three times as much light as single lenses formed of the same glass; and an engiscope, consisting of four, five, or six glasses, &c. four, five, or six times as much, under any given illumination.

The question of the comparative light of reflecting and refracting instruments has been often agitated, and generally determined in a very unfair way by the champions on both sides. The amateurs and makers of refractors, led away by their hatred and contempt of the reflecting tribe, have gone the length of asserting that an achromatic engiscope, having a sextuple, or two triple object-glasses, has fully four times as much light as a reflector of the Amician construction, having the same power and angular aperture ; and that another having an octuple object-glass, composed of four double achromatics not cemented together, has still more light, *cæteris paribus,* than the sextuple one* ; a quantity of light being, I suppose, gained, *not lost,* by the refractions of the two extra glasses. I merely quote these opinions to shew to what lengths a bigotted zeal for any particular kind of instrument may carry even very clever opticians. The opposite faction, exasperated at the quantity of dirt and calumny thrown in their teeth, will naturally take up the cudgels for their darling principle, and retort in the same style upon the imperfections and blindness of the refractors, until the affair becomes a contention for victory instead of truth.

Let us see if there is no way of determining this question in a natural and philosophic manner.

The late Mr. Charles Tulley, of Islington, (whose like we shall not see again in a hurry, and than whom I never met with a more candid, gentlemanly, and scientific optician, ever ready to do justice to every thing and every body), assured me that he had been at great pains, and made many experiments, to determine the comparative light of reflectors and refractors, the results of which I shall state. His favourite method of experimenting (and I do not see how a better or fairer can be employed), was to charge a reflector and a refractor with the same power, and to direct both to a printed bill, placed at an

* A discovery of the late Mr. W. Tulley.

equal distance from each, on a clear evening; and as the light gradually diminished, to see how long he could read it in each: in an instrument whose light or penetrating power was superior to the other, he could distinguish the letters long after the other had become too dark to permit him to do so: but where the light of both was equal, or made so by reducing the aperture of the brighter one, the power of reading in both faded away at the same time as the twilight gradually deepened.

After many trials made by himself in company with other persons, he arrived at the conclusion, that a refractor having a double object-glass of five inches aperture had as much light as a reflector of the Newtonian construction of eight inches aperture, *cæteris paribus;* and the light being in the ratio of the *square of the apertures* was therefore as 25 to 64. Thus, where the apertures of a reflector and refractor are equal, the light of the former is represented by 25, that of the latter by 64: or it may be expressed thus,—the light of the reflector is to that of the refractor as 1 to $2\frac{14}{25}$. Now, it can scarcely be necessary for me to observe, that the Amician catadioptric engiscope is a Newtonian telescope, made on a very small scale, reversed, and that its light must therefore be the same, with this difference, that the diagonal metal being much larger than in the Newtonian, arrests much more light. Its proportional diameter varies in the Amician in different sets of metals, and with it the size of the blot in the middle of the visual pencil. In the pair of 55° of aperture, and in that of 13°, it is one-third of the diameter of the elliptic one; but in that of 36°, one-half. Mr. Cuthbert has sometimes made metals of 41° of aperture, with a *focus beyond the tube;* in such the size of the small metal is necessarily increased, so much as to leave only the mere margin of the concave in operation: on this account they are very dark indeed, as much so as their worst enemies can wish; but metals of this aperture ought always to be made on the same plan as those of 55°, in which the slider is passed

through the tube, because in this construction the size of the diagonal can be kept somewhat under a third of that of the elliptic one.

I have thought it right to allude to these circumstances, because many would think it perfectly correct to pitch upon such a pair of metals as I have described, as a fair specimen of the whole. "*Ab uno disce omnes.*."

In the Newtonian telescope the diameter of the diagonal is generally one-seventh of the other: thus, in one of seven inches aperture the plane is one inch; it therefore only arrests 1-49th part of the whole light, and this is of course considered in Mr. C. Tulley's estimate aforesaid; and if we want to know how much darker the Amician engiscope is than the Newtonian telescope, we have only to calculate *how much more light is arrested by the diagonal in the one case than in the other.* Now where the plane is 1-3d of the diameter of the concave, it arrests 1-9th of the whole; but in the extreme case, where it is one half, it stops one quarter: therefore, where the light of a Newtonian is rated at 25, the light of the Amician will in the first case be represented by $22\frac{2}{9}$, and in the latter by $18\frac{3}{4}$. But in order to obtain the light of the Amician, we must deduct the 1-49th from the 1-9th and 1-4th of the light stopped by the diagonals of the engiscope, and the account will stand thus:—

$$\frac{1}{9} - \frac{1}{49} = \frac{40}{441}$$

$$\frac{1}{4} - \frac{1}{49} = \frac{45}{196}$$

Therefore $\frac{40}{441}$ of $\frac{25}{1} = 2\frac{118}{441}$ deducted from 25, leaving $22\frac{323}{441}$, represents the light of an Amician in an *ordinary case,* compared with a refractor of the same aperture having its light estimated at 64; and $\frac{45}{196}$ of $\frac{25}{1} = 5\frac{145}{196}$, deducted

from 25, leaving a residue of $19\frac{15}{196}$, represents its light in an *extreme* case. Now if we compare the aforesaid numbers against 64, the representative of the light of the refractor, the results are, that the light of the reflector in an ordinary case, compared with that of a refractor, is as 1 to $2\frac{176}{200}$; in an extreme one, as 1 to $3\frac{119}{3775}$: and be it remembered, this is when it is compared with a refractor consisting only of ONE DOUBLE OBJECT GLASS; but there is a confounded deal of difference between the light stopped by four surfaces and that arrested by twelve or sixteen, as will soon be discovered by any one who experiments fairly; and even when an object-glass consists of two or three double ones, with their inner surfaces cemented together, there is still a loss of light to a very considerable extent beyond that occasioned by one uncemented double one*.

They who think I have not darkened the reflector sufficiently can experiment for themselves, by trying refractors and reflectors against each other in a clear evening, taking care to place the instruments in the same aspect, so that the light whereby they are illuminated shall come from the same part of the sky which is always darkest at the zenith, and lightest in the west, low down in the horizon, where a rich saffron tint

* According to the calculations and experiments of Sir W. Herschel, in his paper "*On the Power of penetrating into Space by Telescopes, &c.*"—(*Phil. Trans.* for 1800, p. 65,) out of 100,000 incident rays, 94,825 only will be transmitted through a lens of glass of the ordinary thickness; hence if two lenses are combined, only 89,918, which, subtracted from 100,000, leaves 11,082, the quantity which will be arrested by every double object-glass, being somewhat more than *one-ninth part* of the whole of the incidental light: therefore we must deduct 1-9th for the light lost by every additional double glass employed, which is a quantity equal to the whole stopped by the small metal ofthe Amician, under order ordinary circumstances. Sir W. calculates, that where a double reflection takes place *at right angles*, as in the Gregorian telescope, out of 100,000 rays, only 45,242 will be reverberated, a loss of more than the half. This statement agrees tolerably well with that of Mr. C. Tulley, but makes the reflectors rather more luminous than he does.

frequently remains for a long time after sunset. *No illuminating lenses or mirrors must be used;* the object-glasses or metals must be directed to the same point of the heavens, and the natural light of the atmosphere uncondensed and unaltered by either refraction or reflection, the sole illumination used. If these conditions are not fulfilled, the experiments made will be good for nothing, as must be evident.

For my own part I consider the question of the comparative light of reflecting and refracting microscopes and engiscopes not worth agitating; and I think the following experiment quite conclusive on the subject:—Take an Amician, equipped with one of its darkest sets of metals and its deepest eye-glass; mount it for viewing some transparent test, or at least something or another requiring great distinctness for its manifestation; illuminate it by reflecting the light of the sky from its plane mirror (an operation which of course reduces the light), and you will find *that dark as the instrument is, it is more luminous than consists with perfect distinctness,* and that you may greatly improve the vision by using diaphragms under the stage, *reducing the light of the field several shades lower.* Again, opaque objects we can brighten at pleasure, by compound illuminators, and lamps fed by oxygen gas, &c. &c.

In telescopes the case is totally different, any defalcation of *their* light being sure to be attended with a serious defect in their performance upon all objects requiring penetrating power, because we have no means whatever of increasing their intrinsic brightness.

It will be found that *a certain angle of aperture in metal is quite equal to the same aperture in glass,* as to its penetrating power in developing the tissue of all sorts of lined or proof objects, when aided by a proper illumination; and I need not say, that with respect to telescopes, such a position is entirely false: therefore there is a wide difference between the relation of the refracting and reflecting principles to each other, when applied to these different instruments; and *the performance of*

*reflecting engiscopes is proportionally far superior to that of reflecting telescopes,** though it is most fully admitted that their natural light or intrinsic brightness is greatly inferior to them. The worst point about reflecting engiscopes, in my opinion, is, not their darkness, but the *brownness* of their light: this is very perceptible in reflecting telescopes also, when used with high powers, and is in both instruments remedied to a certain extent, by using eye-glasses of crown glass instead of plate.

In the Amician, used with day-light, it causes objects, or rather their images, to appear just as if they were depicted on *brown academy paper*; and the effect is very disagreeable, compared with vision by refraction, which always shows them as if executed on *white paper*. A connoisseur may discover merit in a drawing on brown or violet-coloured paper, but the vulgar will hardly look at it; the prevailing tint disgusts them at once.

It is, however, a most fortunate circumstance, that this brownness in the light of reflecting instruments wholly disappears, or at least becomes insensible, when they are used with artificial light; in consequence, they are thus seen to the greatest advantage, and as we now have lamp-light brightened to perfect whiteness by oxygen gas, for microscopic purposes, and nearly equal to day-light for such objects as agree best with it, the reproach of a brown image will be in a manner done away with altogether from reflecting engiscopes.

* Whoever will be at the pains to look into the state of the figure of the metals of reflecting telescopes, and compare it with that of the elliptic metals of engiscopes, will find the latter (if they have been well executed) far more perfect than the former; for their figure being very nearly allied to that of a sphere, and moreover having a great depth of curvature, can always be kept from degenerating into that state of flatness at the edges which produces over-correction by giving the outside rays too long—a defect which seems almost inseparable from reflecting telescopes.

As Dialogue is that mode of writing in which a variety of contending opinions may be most naturally brought forward and answered, I have selected it as the best way of discussing the comparative merits of instruments: if the reader must know the names of the parties, I beg to inform him, they were Tobias Oldbuck, Esq. the naturalist, and Mr. William Putty, the optician. Lest I should be accused of putting nonsense into the former gentleman's mouth, I must state that he only expresses opinions current among the observers of this enlightened age, and which I have frequently encountered in society.

I must positively introduce my personages to the reader. Mr. O. is an old bachelor of about 60 (a descendant of the Oldbucks, of Monkbarns). He always wears a very natty wig, made by an eminent artist; his clothes are of the true scientific brown-study colour; he has not altered the cut of them, or the model of his hat, or any of his opinions on any subject, for the last ten years, and declares he never will, thinking it beneath his dignity either to learn or unlearn any thing at his time of life. Having described his costume—that outward and visible sign of a man's character, and which, indeed, conjointly with the periwig (which I have sufficiently described), constitute the man—I do not think it necessary to say any thing more about him, except that at one period of his life he was far gone, and most intently engaged in constructing achromatic object-glasses for microscopes, which, however, he abandoned as an impracticable bad job: when another person afterwards succeeded in producing them, Mr. O.'s pride was wounded in the tenderest place, for he considered himself a perfect giant in all sorts of microscopic science; in consequence, the sight of an engiscope ever after turned his stomach.

Mr. William Putty is an enthusiastic young optician, whose talents are of the first order; he has originated many capital improvements in microscopes, of which instruments he is very

fond; thinks we live in the golden age of these matters, and that we have left our ancestors far behind in all things pertaining to them. His character the reader will find is a complete contrast to that of Mr. Oldbuck.

Now it came to pass that one wet day Mr. O. was walking up and down in his study, occasionally surveying his wig in a mirror, and somewhat ruffled in his temper by the impertinence of the junior members of a learned body to which he belonged, who worried him, till (much against his will) he was forced to look into a very fine achromatic engiscope, which showed objects *too well* to please him. To vent his spleen he was indulging himself in the following soliloquy: "What occasion have I, or any man, for any other microscopes than single ones? vision by these is so perfect and satisfactory to me, that I want nothing better. *Was there ever any thing so ludicrously preposterous, as forming the image of an object, and viewing it by a species of microscope, called an eye-glass, instead of looking at the object itself with an eye-glass?* Are we not content with seeing nature itself? would any rational being rather behold a picture of a beautiful woman or landscape, than see the reality? What a monstrous perversion of all taste, to prefer art to nature! it seems to me little short of insanity itself. Away, then, with this nonsensical trumpery, and let me alone with my good, old-tried, staunch, simple microscopes."—Here Mr. Putty was introduced, who had brought home some trifling job; he met with rather a frosty reception, but instantly took up the word thus:

"But, my good sir, admitting the justness of your observations, these simple microscopes of yours are very imperfect things, generally equi-convex lenses of plate glass; by making them of other substances of higher refractive and lower dispersive power, they may be greatly improved."

"I shall not deny the truth of what you say, Mr. P., *theoretically speaking* at least, but I have looked through lenses made of diamond and other precious stones, but cannot satisfy

myself that I see any better with them than with those made of glass. Here, examine this opaque object with a single equi-convex lens of glass, having an angular aperture of 55°, set in a small silver cup; its sidereal focus is only one-thirtieth of an inch; or take this, it is one sixtieth of an inch, set in the same way, and has an aperture of one-sixtieth of an inch or 55° also? did you ever see any thing more distinct: the object is the scales of the diamond beetle, and would, from its brilliancy, be sure to show the aberration of the lens, if it had any, but you see the scales perfectly clear and distinct; will you pretend that such vision can be improved?"

"The vision is more clear and satisfactory than I could *à priori* have thought possible; but I do not see the lines on the scales well made out; on many of the scales, begging your pardon, I cannot see them at all."

"That is not the fault of the lens, but of the method of illumination, which is not of the kind required to bring out lines."

"But illumination has so wonderful a power in modifying the vision of many objects, especially those of the test kind, that it will sometimes make the better instrument appear the worse, and the worse the better; now, I could show you the said lines much better in an engiscope, because I can illuminate objects in such an instrument (especially opaque ones) any how I like; though I grant that I do not show you the lines themselves, but only a picture of them; so exact, however, that"—

"It will not impose upon me; I do not choose to trust to *pictures*, especially when I am exploring *unknown objects*; your engiscope (as you call it) may do vastly well to exhibit *known ones* to a parcel of women and children."

"Then you admit it to have the power of showing *known* objects; how and in what way can you ascertain that even your dear single magnifier can be trusted upon unknown objects, save by the experience you have had of their per-

formance upon those you are acquainted with? Your dogmatizing is an insult to reason and science, and unworthy of a reply."

"Well, I will admit (just to put you in humour again) that an engiscope may show such things as the lines in question rather better than my single lenses, but I should be glad to know if you can show me any *transparent object* better than they do, with any other sort of instrument; (now I have you on the hip.)"

"I perceive you are too much prejudiced against engiscopes, from *à priori* considerations to do them justice; they *ought to be* inferior to single magnifiers you think, and therefore you will have it they *must be so, and are;* but have you ever used compound magnifiers? they show you the real object as well as the single ones; and when scientifically made, are thought, by excellent judges, to perform much better, inasmuch as their aberration is far lower than that of equi-convex or even plano-convex lenses; in short, they would seem to afford us the *ne plus ultra* of perfect vision in contemplating minute objects under large angles."

"I have not used them much; they are things of great antiquity, and have been both in and out of fashion with naturalists many a good time and often, before now: when their power is high they are very inconvenient in the ordinary course of microscopic researches, from the closeness of them, when in focus, to the object; indeed, this circumstance precludes their use on opaque bodies altogether, and I candidly tell you, that when an instrument will not show opaque objects well, I am apt to reject its use altogether."

"In this you are very unjust. It is a law in optics and most other things, that when we gain an advantage one way, we must in general be content to lose it in another; it only remains for us to choose of what kind the advantage shall be; we must have one kind of instrument for one set of objects, and another for another, if we wish to avail ourselves to the

utmost of every good within our reach. To reply point-blanc to your former question, will you be content to admit the superiority of doublets and triplets, if I show you something with them in a decisive manner, which you will hardly be able to see at all with one single lens out of twenty, and then only in a most imperfect manner?"

"I don't know: I am so confident of the excellence of my own lenses, that if you were to shew me any thing with another instrument, which I cannot see with them, I should be disposed to set it down *as an illusion of some sort or other*; and if you were to shew me any thing *in a different manner* from what they do, I should be very much inclined to think that they were in the right, notwithstanding."

"I thank you for your candour; this is precisely the way that every man *thinks* with respect to his favourite instrument, be it what it may, though he may not dare *to speak out* as you have done; it is 'poor human nature all over.' But, sir, this method of reasoning—I cannot see such a thing in my microscope, *ergo* it is an illusion; or, another man's microscope shews an object different from mine, *ergo* it shews it wrong, cannot be tolerated;—it may become a fine lady to talk in this manner, but in a pretender to science it is insufferable."

"Well, what is the wonder you are going to shew me? I suppose it will turn out to be the oblique lines on the brassica, you are always making such a fuss about,—an isolated instance, supposing the said lines actually to exist. I certainly have seen a few of the lines you allude to, with a doublet of about 1-20th of an inch focus; but, in general, doublets and triplets shew no more of them than single lenses do."

"I see plainly I shall have to fight the ground inch by inch with you; but I shall not despair of gaining the victory at last, 'if I have a fair field, and no favour;' at least in the opinion of impartial and unprejudiced bystanders, if any such there are. You say you have seen the lines in question, or

the *ghost of them* at least, with a doublet: now, have you seen as much with any of your adorable single magnifiers?"

"I have seen them occasionally, when they have been of very superior quality, and exquisitely set with a large aperture; but, I freely own, not with sufficient distinctness to convince me of their existence. The appearance somewhat resembles the tissue of a coarse piece of canvas, with the fibres running diagonally, when it is placed too far off from the eye to allow us to recognize the threads distinctly. The doublet makes this difference, that a thread here and there seems stronger and coarser than the rest, and therefore more distinct; but, as I have already observed, I am strongly disposed to think the whole an illusion, produced by oblique light."

"Have you ever seen the French brassica? The traces on it are still more difficult to exhibit, or fainter at least, than those on the English variety, particularly on that kind which is of the form of a heart, or like the head and tail of the other kind, abruptly joined together without the intervening portion; these may be said to make two other objects of the same kind. And now please to *prove* to me that all these are illusions: the *onus probandi rests with you,* and what arguments you are to use for that purpose I cannot imagine, unless they are *such as will equally serve to disprove the existence of any other delicate traces on tests in general:* beware of proving too much; many a logician has overreached himself in this way."

"I was trying against each other the other day three magnifiers, a triplet of 1-40th of an inch, a doublet of 1-70th of an inch, and a single lens of 1-60th; with none of these could I see the diagonal lines in question: all other lines and objects they shewed admirably well, and their performance seemed to me precisely alike, except, of course, as to power: all were made with the utmost care by a workman of the highest eminence, and were indisputably of the very first quality;

the apertures of all were fully 55°; the triplet I think more, 60° about. Now, sir, I candidly tell you, that I cannot believe that these three capital magnifiers would all agree in passing over unheeded the lines we are arguing about, if they really did exist, and allow a doublet, and a single lens of 1-20th inch focus, to have the merit of shewing them. It is this circumstance which staggers me—the conflicting testimony of various instruments and lenses; I am puzzled, as I should be were two highly respectable witnesses to aver they had seen such and such an event or thing, and two more, at least equally worthy of evidence, to assert that the actors in the affair were, to their knowledge, twenty miles distant from the place where it was said to have occurred at the time."

"You will frequently find a similar discrepancy in the performance of very excellent telescopes upon certain objects; the pole-star, for example. I have seen many excellent instruments of this class with large apertures, which shewed double stars, nebula, and clusters, in perfection—nevertheless, as blind as young puppies on this particular object—which a good achromatic of only two inches aperture will often shew; yet no astronomer has ever had the hardihood to deny the existence of the small star near *polaris*, or term it an allusion: a fine pickle, truly, would astronomy be in, if every observer had the privilege of denying the existence of every heavenly body he could not see in his favourite telescope!"

"Well, sir, suppose I concede to you this point in favour of compound magnifiers, what else have you to urge on their behalf?"

"I conceive it to be a just inference that they do actually exhibit all sorts of lined and ordinary objects better than single ones, though, from the coarseness of many of them, and the want of a requisite delicacy of apprehension in our eyes, we are not able duly to appreciate their performance on all occasions alike. It certainly happens to be the case, that the diagonal lines we are talking about are a sort of solitary in-

stance of the superior penetration of doublets; but if they had chanced to exist in the whole tribe of tests, then most certainly would the single lenses pass them over in all alike, and the doublets bring them out; at least, when of the requisite goodness. Let us suppose a telescope to be gifted with a sufficient power of penetrating into space to be able to shew the sixth and seventh satellites of Saturn, and that there happened to be no other bodies requiring an equal degree of illuminative power for their manifestation; then, perhaps, would the invidious assert that they were very probably some illusive appearance or another, as the telescope was not capable of shewing any other objects better than ordinary. I need not say how senseless, unscientific, and unphilosophical, such a conclusion would be; however, there is, as I think, another mode of demonstrating the superiority of compound magnifiers, which you will be satisfied with, sceptic as you are."

"Sir, I am all attention; what can this be?"

"Will you admit that the fact of our being able to discern some difficult test with a very low power is a proof of the goodness of the instrument we employ, and the lower the power the better the instrument?"

"It is certainly a very great convenience to be able to do so at any rate, and I should not hesitate to say myself, that an instrument which will shew me every thing I want to see, without forcing me to employ high powers, is, at least, a most useful and valuable implement for a naturalist, for a thousand obvious reasons, whether actually better or not than another which requires a higher charge of power for the same purpose."

"Well, then, here is a doublet made upon truly scientific principles, being the compound aplanatic lens of one kind of glass of Sir J. Herschel; its focus is one-sixth of an inch. Compound magnifiers, believe me, are at present far from that state of perfection to which they are capable of being brought, because the makers of them are generally pleased

to vie with each other in trying who can insult science the most grossly in the principles which they adopt, though I grant that they work excellently well, according to them. Now, with this magnifier I think you will find that you will see tests which cannot be discerned with any sort of single lens of the same focus and aperture, nor with this either, if you choose to reverse it, or turn either of the glasses the wrong way, so as to subvert the principle on which it is made."

"I like this sort of test a great deal better than the diagonal lines on the brassica; the name of Herschel carries with it weight and authority. I will verify the facts you state at my leisure; but I must give full loose to my scepticism in the meantime, and assert that I believe microscopes may be very good, and perfectly to be depended upon for making discoveries in all the ordinary branches of natural history and microscopic research, which will hardly shew any of these precious things you have set up as tests: a plague upon them! are we to be eternally bored to death with the dust of butterflies' wings and the scales of beetles? for my part I don't value them a rope's end?"

"Then you deserve to be made to appreciate the uses and properties of a rope's end at their full value; nevertheless, I will myself so far agree with you that I consider the whole family of lined tests as very exclusive sort of objects: it is very difficult to find others requiring the same penetrating and defining power; therefore the individual who first discovered and introduced them to the notice of the public, associated with them others, especially some difficult ones of the opaque class, which I hardly think any reasonable person can refuse to admit as proper tests for all microscopes, of what nature or kind soever may be the researches in which they are to be employed: such are the minutiæ of a fly's foot, the serratures on a human hair, the little pits on a mouse's hair, the tissue of the moss hypnum, and to these must certainly be added the eyes of several animalcules. If an instrument cannot

shew these, I suppose you would reject it as unworthy of confidence?"

"My dear sir, you now begin to talk like a rational being; I cordially agree with you: *all these things single lenses will shew in perfection.* Do you know I had such satisfaction the other day in shewing a young puppy the eyes of a wheel-animalcule with a single equi-convex lens: he thought, forsooth, to have come over me with his thingamy, his hang-his-cope, as I think he called it.

"You must not forget, that even the objects you admit as indispensable proofs or tests are not shewn, except by instruments likewise capable of shewing the *majority* of the lined ones, and that their goodness would be as well demonstrated by the lined objects as by a fly's foot, &c.; whatever shews the one will be sure to shew the other."

"Well, well, be it so; I am glad to find that we can go along with each other to a certain extent; and I hope you will appreciate my long experience and long habits of research, with regard to the minutiæ of natural history, as worth something, and that I have not adopted the opinion that single lenses are, upon the whole, *the most useful and effective working microscopes*, rashly. I shall always be ready to admit *theoretically* the superiority of compound magnifiers; but I believe it is only when they are of *a certain focus and aperture* that the eye really derives any advantage from the use of them."

"Have the goodness to explain yourself; I really do not comprehend your drift."

"Why, simply this: here are some equi-convex lenses, (very useful ones I find them), of $1\frac{1}{2}$ inch, 1 inch, and $\frac{3}{4}$ inch focus; I mean to say that I find no use in employing them with a larger aperture than that of my iris; and when thus reduced, I see no aberration about them; a little colour only is perceptible with an oblique illumination; they are, in short, as good as need be,—the finest doublet or triplet of the same

focus and aperture seems no better: if I even use an achromatic glass corrected by a concave lens, my vision does not seem to be improved, *because the aberration of the equi-convex lens was already quite insensible* to me: you see what a deplorable animal you have to deal with! You set before me a *salmis de becasses à la suprême,* and a bottle of *clos vougeot* to wash it down; and I think a beefsteak and a pot of stout as good or better food."

"There is some shew of reason in what you say, as we generally like any kind of food to which we have been habituated, however coarse it may be,—so do our eyes become coarse and indelicate in their perceptions, and satisfied with very ordinary glasses, from the effects of long habit; but of course, when we come to high powers, you will then admit the superiority of the compound glasses.

"Not at all: when we come to lenses of 1-30th, 1-40th, 1-60th of an inch, and upwards, it appears to me that their aberrations are so very trifling as to be insensible, even when only equi-convex. You saw how distinctly the 1-60th of an inch lens shewed the scales of the diamond beetle in the outset of our conference: I do not believe any practicable doublet would act any better; but it would, as you know, be impossible to get a doublet of this power *to shew an opaque object at all,* so the experiment could not be fairly tried. I have already told you the result of my trial of the doublet, triplet, and single lens, on the diagonal lines of the brassica; and to conclude, I verily believe that it signifies very little when we come to these high powers, whether they are obtained by single or compound glasses."

"Then do you actually mean to deny the superior efficacy of compound magnifiers altogether in all and every case: this is too bad!"

"Not exactly; that would drive you frantic altogether: I do think that there is a certain range of power, from about ¼ of an inch to about 1-20th, at which the eye is capable of

appreciating their superiority, and consequently of deriving advantage from it, (though it may not be much). When a lens, having a large angular aperture, is not of greater diameter than the pupil of the eye, so that all its marginal rays shall operate fully, it will, if free from aberration, make its goodness felt and recognized, provided, as I have already said, it does not run to an extreme in point of depth: now, in the aforesaid range of power, these conditions will occur; and it may perhaps be considered that the circumstance of the diagonal lines being best shewn by doublets of *about* 1-20*th of an inch focus,* and rarely by deeper ones, as well as the striking efficacy of the compound aplanatic of 1-6th of an inch focus, are a sort of confirmation of my hypothetical notions, on which, however, I shall not insist."

"Well, I am glad to be able to extort this unwilling confession from you, at last; I suppose you would consider single lenses, made from substances which naturally give as low an aberration as doublets and triplets, in the same predicament with them; and that you have no better opinion of diamond or sapphire lenses, or even of compound magnifiers made of them: indeed you said as much just now."

"How can I? I must of course be consistent in my principles; you will have a confounded hard task to prove their superiority in any other way than by reference to analysis, believe me."

"With such bigotted, obstinate, sceptics as yourself. But let us drop the subject of compound magnifiers: will you come and look at a beautiful aplanatic engiscope?"

"A what? stuff and porridge! prythee, leave off this ridiculous slang, and speak plain English."

"Well, then, a compound microscope,—but of wonderfully improved construction."

"I have no desire to see it: in the outset I told you my mind about these awkward unwieldy things; I can assure you

it has long been made up on the subject: and though I fully admit the magnitude of the improvements made of late on these instruments, and their superiority over the old ones, I consider them useless; except, perhaps, for the purpose of executing micrometrical measurements,—for which end I do not deny that they are somewhat more convenient than simple microscopes: however, we can measure the size of objects perfectly well without them."

"If you will not allow them any merit in an optical sense, you must admit that they are vastly more convenient than simple or compound magnifiers, for a variety of other purposes, as well as in executing micrometrical measurements, owing to the room they create between the object and the glass:—for dissecting; viewing bodies placed at the bottom of cavities; looking through the sides of a glass vessel containing polypi, chara, and aquatic insects; examining small parts of large bodies, not detached from their wholes, as opaque objects, and the like?"

"All these things can be done with single lenses also, *of the ordinary working powers:* I repeat, their assistance can be dispensed with."

"What say you to their large field of view? Is their achromatism also without merit?"

"I say that their field is no larger than that of a single lens, provided it is *so set that it can be brought very close to the eye;* for then, *by turning the eye about, an equal number of degrees of field can be examined:* the only difference seems to be, that in the compound microscope or engiscope, as you are pleased to miscall it, *the whole field* is taken in *at one swoop.*"

"That makes a vast difference, let me tell you: but will you not admit that the engiscopes fatigue the sight less than single magnifiers, when the power is high?"

"That is entirely an affair of habit; my eye is never

fatigued with the deepest single magnifiers: whatever instrument shews an object best will fatigue the sight least, be it what it may, as must be self-evident."

"I see you have rolled yourself up like a hedgehog, and present nothing to me but a ball of prickles, let me turn you over which way I like: however, if you are not afraid of meeting with an instrument you may chance to like better than your own, pray look at these scales of the podura in the engiscope."

"Afraid, indeed! a likely joke."—[*He looks.*]

"Can you say you have seen this object as well in your single, or I will say compound, magnifiers? say, on your honour!"

"I cannot say, upon my honour, that I have seen the lines so dark, and so decidedly made out; but the circumstance is easily accounted for by the *superior darkness* of the engiscope, which I need not say must be much greater than that of a single lens of the same power and angular aperture, having, of course, an opening equal in size to the visual pencil of the engiscope."

"Well, sir, that circumstance need not distress you; if making instruments darker will cause them to perform better, we can, God be praised, darken your single lenses for you to any required degree, with coloured glasses; but I will defy you to shew the object with them as you have seen it just now, do what you will with them; *not only are the lines shewn darker, and the spaces between them clearer, than with your lenses, but many which with single or compound magnifiers, of high powers, seem ragged and dotted, or rather an aggregation of dots, are shewn as veritable lines*; moreover, *you see the outline of the scale best at the same adjustment which serves also to bring out the lines**."

* My coadjutor, whose experience is very great, assures me, that this circumstance depends upon the state of correction in the objective as to sphericity,—the aberration of which must be overbalanced to exhibit the

"That is because the magnifiers shew them right, and the engiscope wrong; I do not believe that the lines on the scale are in the same plane with the margin of the scale, though they may be *nearly* so."

"Here is the old object, the diagonal lines on the brassica; look how strongly they are made out, and how *many more of them are visible than with the best doublets or triplets.* Can you doubt of them, really, now? Look, how beautifully, by a slight change of the light, all the cross stria come out."

"I told you before, engiscopes must not be trusted for exploring unknown objects, or making discoveries; the whole is an illusion."

"You say engiscopes cannot be trusted to make discoveries, *behold! they make them for you, and you will not believe in them.*

"I see your patience is nearly worn out, I will not plague you any more, except to view the diagonal lines on the brassica IN THE INSTRUMENT WHICH DISCOVERED THEM—THE REFLECTOR OF AMICI; they are shewn so decisively in this instrument, that *it would be as reasonable to doubt their existence as that of ruled lines in a copy-book:* doublets and *achromatics sometimes shew them, sometimes not,* but THE REFLECTORS NEVER CONCEAL THE TRUTH: moreover, *observe the perfectness of the longitudinal lines;* NO DOTS!"

"Pooh, pooh, man! of course the reflectors being still darker than the refracting engiscope, naturally shew these and all other objects darker; and this you call shewing them better."

Here Mr. Putty, who was one of those persons who can, on ordinary occasions, laugh in their sleeves without moving a muscle, and who had been long much tickled with Mr. Old-

grooves and contour together: again, a variation occurs according to the side of the scale which is viewed.

buck's humours, was fairly upset, and burst into a long scornful laugh; which Mr. Oldbuck, who mortally hated and dreaded any thing like ridicule, resented, as a gross piece of ill breeding, and an affront to his dignity; and so the conference terminated, both parties being unconvinced by each other's arguments, and remaining in their original opinions; Mr. Putty considering his engiscopes a signal instance of the glorious triumph which it is possible for art to achieve over nature, by the *destruction of aberration;* thus creating an instrument which, though it operates through the medium of an image, but of almost inconceivable perfection, is nevertheless capable of exhibiting all objects more perfectly than can be done by the best magnifiers; at least when the artist has been so fortunate as to produce a perfect system of object-glasses, with their aberrations exactly balanced, or a pair of metals exquisitely figured: Mr. Oldbuck, on the other hand, regarding them as a mere waste of labour, and prostitution of talent, quite unfit for philosophical purposes.—C. R. G.

POSTSCRIPT.

It only remains for me to say, as an epilogue to this little scene, that I have expressed my own sentiments in the character of Mr. Putty; and though I have formerly, in a paper in the Quarterly Journal of Science, given it as my opinion that it would be utterly inconsistent with the laws of nature and optics that engiscopes should ever equal the performance of magnifiers applied directly to the object, yet I am now convinced by facts, that those *now* made not only equal, but are capable, in a few rare instances, of surpassing them, especially if of the reflecting kind. The only instance I can point out in which an engiscope fails to do its duty, or what I

suppose to be such, is this:—we all know that a globule of quicksilver, like a convex mirror, forms a miniature image of every thing it is exposed to; a window for example: we know also, that we may, with a powerful engiscope, view, and magnify, and examine, this minute image, *provided the globule is not too small;* if it is, the engiscope makes a *blot* of light of it (like the spurious disc of fixed stars seen with a powerful telescope), instead of developing the features of which it is composed, for there can be no doubt that the most minute globule forms an image. A reflecting instrument, indeed, gives a smaller spurious disc than a refractor, and will also define the image of a smaller globule, but still, it fails at last. Now, whether magnifiers of high power would do the same thing or not, we have no very accurate means of knowing; for they approach so very near, when applied to objects, as totally to overshadow them, and thus preclude the formation of an image on the globule, except by means of a cup; and the illumination of the globule being accomplished in this way, of course we can expect to see nothing but the *image of the cup*, which may easily be mistaken, when on a very small scale, for a spurious disc. Now I have sometimes thought that this property of engiscopes causes them to give that appearance of dots or specks so visible in the tissue of the lines and markings on the grooved proof objects, especially the brassica, when viewed with aplanatic object-glasses *of great depth;* so that a small effort of the imagination would easily enable us to fancy that we actually saw the constituent particles or atoms of which the body was composed. This phenomenon may, with old specimens of scales, be, in some measure, owing to decomposition; at the same time reflectors cannot be said to shew it, but *there is no knowing what they might do if their objective part could be rendered of the same depth as that of the refracting instruments.* As to compensating for this deficiency, by *forcing* the power with eye-glasses of very short focus, it is a practice I have always reprobated, as it dilutes the image till, in my

opinion, there is very little reliance to be placed upon its demonstrations. The best doublets, triplets, and lenses of gem, seem to shew the dots and points much in the same way as the refracting engiscopes, but perhaps not so strongly marked. As for the reason why refracting instruments so rarely shew the oblique lines on the *Picris Brassicæ*, and when they do, perform their task in so slovenly a manner, I must confess I am as much at a loss as why metals, having a large angle of aperture, should *so invariably* exhibit them; unless the reader is pleased to lay the circumstance to the account of the superior defining power of the reflecting instruments. Perhaps there may be some analogy between this object and the small star near Polaris, which is frequently shewn by small telescopes possessing great defining power, and passed over by others of large aperture, which shew all other telescopic objects perfectly, such as the minute stars composing clusters, and the like, which we should suppose *à priori* quite as difficult to bring out. This star seems also to melt away under the action of high powers, whereas there are others, to all appearance vastly like it, which cannot be seen till the field of view is rendered very dark, by a high power (*vide* Sir W. Herschel's Catalogue of Double Stars, in the Transactions.) I may observe, that I never saw these oblique lines with a power exceeding that of a 1-40th of an inch lens: all the *very deep* object-glasses and doublets I ever happened to use were totally blind with respect to this very remarkable object.

C. R. G.

CHAP. VI.

ON THE SPHERICAL AND CHROMATIC

ABERRATION, &c. OF EYE-PIECES.

It being still stoutly maintained that engiscopes and erecting eye-pieces, having foci in front of their anterior glasses, can be rendered achromatic by merely arranging their component lenses at particular intervals; and that "the intellectual and manual labour which has of late years been expended on the construction of achromatic object-glasses has been, in consequence, unprofitably directed*;" it is the province of the present work, and the bounden duty of its authors, to demonstrate the falsity of such doctrines, and to vindicate the truth of the

* *Vide* a Paper in the "Philosophical Magazine, and Annals of Philosophy," for August, 1831, No. 56, p. 112,—*On the Theories of Achromatization, by the Rev. H. Coddington*, in reply to a paper published by myself, "On the Chromatic and Spherical Aberration of Eye-pieces," in *Sir D. Brewster's Edinburgh Journal of Science*; in which, as it was in separate circulation at the time, Mr. C.'s answer certainly ought to have appeared, *unless it was intended to be read by itself, without reference to the paper it pretends to refute.* Mr. C. yields but one point, viz. the theory of the Gregorian telescope, constructed with mirrors of glass, which he admits to be somewhat imperfect. I think it will generally be found that if a man has an imperfection in his understanding, or method of analysis, which will cause him to be in error on one optical subject, it will operate on a vast number of others. The only favour I have to request of opticians is, that they will read the paper I have alluded to, or the present one, in conjunction with Mr. C.'s *candid and ingenuous* answer. In the former there are many typographical errors, which confuse my meaning in some places.

opposite principles, for the honour of the improvements lately introduced into use. If, indeed, the said dogmas and theories had been laid down by obscure individuals without influence, it would have been the wisest course to have allowed them to rest in peace and contempt; but, unfortunately, their authors are persons of the highest consideration and influence in the scientific world, by whom they are supported with all the parade of mathematical demonstration; and it may not without reason be expected that a large majority of that class of *savans*, who dare not, and perhaps cannot, think for themselves, will conceive it to be much more creditable to be in the wrong with men of such high eminence, than in the right with mere practical opticians. Yet it must be admitted that optics is both an experimental and demonstrative science, and it is well that it is so; and though experience ought certainly never to dictate to analysis, (which would be placing the cart before the horse, with a vengeance), yet, the testimony of the senses, and of those organs which are to use optical instruments, must not be wholly rejected. A telescope, and what is usually termed a compound microscope, or engiscope, pass into each other by insensible degrees, so that it is somewhat difficult to define the one from the other otherwise than by drawing a line of demarcation between them by reference to the length of the anterior and posterior focus of the object-glass: thus we may say that a telescope has its anterior conjugate focus, or the distance of the object from the object-glass, longer than the posterior, or that next the eye-piece. In an engiscope the case is reversed; perhaps, therefore, a definition of an engiscope, as distinct from a telescope, may be given thus:—it is a telescope made on a very small scale, having its object-glass, and the conjugate foci thereof, reversed. In support of the analogy between the two instruments, it seems proper here to remark, that an engiscope will act with a concave eye-glass just as a Galilean telescope, and that its focus can be adjusted by moving the eye-glass alone, instead of the whole body, as is usually practised.

The line of separation between them is where the two foci are equal: such being the case, we may make an object-glass of short focus, say four inches, gradually pass through all the gradations from a telescope to a compound microscope, without making the least change in the principle on which the image is formed. Now no optician has ever yet dreamed of making an achromatic telescope by arranging a system of glasses at particular intervals; though, if a compound achromatic microscope or engiscope can be so made, we ought surely to be able to construct a telescope, of some sort or other, on the same principle; the two instruments, as before stated, being so similar in their action of forming an image. It is a consideration also worthy of being attended to, that the first practical opticians in Europe have now all adopted the method of making achromatic engiscopes precisely on the principle of telescopes; that is, by *correcting the objective part by means of concaves of flint glass.* Such men as Fraunhofer, Utzneider, Amici, Selligue, Chevalier, Dollond, Tulley, would scarcely have all adopted so difficult a task as that of making these minute achromatic glasses, if it had been possible to obtain a perfect correction of chromatic and spherical aberration without them. They are all in the habit of making so-called achromatic erecting eye-pieces for spy-glasses, which are, in fact, nothing but compound microscopes; and it is hardly credible that they should not have perceived the application of them as such, if they were *bonâ fide* achromatic. But the fact is, these artists all know the fallacy of these things, and how, and under what circumstances, they are achromatic. I propose to shew that an engiscope cannot be made achromatic in any other manner than as a telescope is, and that the new achromatics are, consequently, not superfluous.

The angle of aperture of the erecting eye-pieces of spy-glasses is usually very small, not exceeding that of the object-glass they operate with, or about five or six degrees; the chromatic aberration, therefore, of what may be considered

their objective part, is nearly insensible to vulgar eyes, on account of this small aperture. For, *cæteris paribus,* the chromatic aberration of lenses is in the direct ratio of the square of their aperture, or the actual quantity of light they admit;—if, therefore, the size of the pencil is restricted to perhaps one tenth of an inch (the usual diameter of the stop between the first and second glasses of an eye-piece), it is wholly impossible that much colour can be generated. But if a lens of thirty inches focus has an aperture of five or six degrees, its diameter will be about two inches, and the quantity of colour generated by it eighty times stronger than in a lens of two inches focus with an equivalent opening. Moreover, it is well known that all working opticians are in the habit of over-correcting the colour in the object-glasses of those telescopes which are expressly made for viewing terrestrial objects. It is supposed by some, that the predominance of blue and purple rays, which is occasioned by this over-correction, tends to exhibit terrestrial objects better than they would be seen if the instruments were perfectly achromatic—an absurdity which I shall not take the trouble of refuting. *The real manner in which a beneficial operation is produced by this over-correction for colour, is by its effect on the eye-piece,* which it greatly ameliorates and improves, by neutralizing the red and orange light which would otherwise greatly preponderate in it, *so that the totality of the instrument may be considered sufficiently achromatic for practical purposes;* nevertheless, under certain circumstances, the uncorrected colour of the eye-piece renders itself very manifest—as, for example, when we view some dark object, such as the rigging of a vessel, or a weathercock against the light of a clear sky; for by placing the object at the edge of the field of view, while we look obliquely at it from the opposite side, so as to catch an eccentrical pencil, the uncorrected colour is instantly felt.

Now, as I am contending for the *principle* of achromatism, I shall proceed to shew that all erecting eye-pieces of the

ordinary construction, though they may, under certain circumstances, and in a practical point of view, pass for achromatic, *yet have, in good earnest, no achromaticity about them;* and of this I think any man may convince himself by the following experiment:—there is a small circular disc of brass, with a hole in it, placed between the two bottom glasses of all erecting eye-pieces, which, when the telescope is in action, serves only to exclude the false light which is reflected by the long tube: the diameter of the hole in it is usually about one-tenth of an inch, or just what will allow the pencil of light from the object-glass to clear it: the telescope will be just as achromatic without it as with it; when, however, the eye-piece is removed from the telescope, and tried by itself, as a compound microscope, the said diaphragm acts a very important part, and, in fact, reduces the angle of aperture of the eye-piece nearly to that of the object-glass of the telescope along with which it acted, being, as I said before, perhaps six degrees. Now it is no wonder that with so small an opening, though unassisted by the over-corrected object-glass, the eye-piece should still pass for achromatic with those who know not how to look into its defects,—just as we see Mulattoes and people of colour, who have not *much* black blood in their veins, pass for whites. Let, however, the said stop be knocked out, or, what will amount to the same thing, let it be opened out with a broach, until it will admit the whole of the pencil of a perfectly achromatic object-glass, *having a large angular aperture*—for example, one belonging to an opera-glass, or perspective, or or some of those dumpy achromatics which Ramsden was in the habit of making—this will probably cause an enlargement of the perforation of the said stop, from 1-10th to 3-4th of an inch, if the focus of the first glass is two inches. It may be known to have attained its proper size when the ratio between the diameter of the visual pencil and that of the object-glass truly represents the magnifying power of the telescope, or, when it is found by examining the pencil with a magnifier, that none

of the aperture of the object-glass is cut off by it. On trying any telescope thus mounted, it will soon be seen whether the eye-piece is achromatic or not: or the said eye-piece may be tried as a compound microscope, by itself; and I can only say, that a man who is not able to perceive colour in it must be either utterly blinded by preconceived opinions, or by a complete incapacity to perceive the faults of optical instruments*.

Nevertheless, *there is a construction for an erecting eye-piece which is* bonâ fide *achromatic to any angle of aperture,* as it appears to me, namely, a *simple reduplication of the Huyghenian eye-piece;* that is, using one to erect and form the secondary image, and another to view it, which will give a compensation to each part; but this construction is never employed, at least I never met with it, because, I presume, if we use a Huyghenian eye-piece to form a secondary image, the component lenses will be nearly of the worst figure, and in the worst position for giving distinctness†,—which is a quality to be preferred even to achromatism. I need not observe that such a construction could never be used by itself, as an engiscope, or compound microscope, because its focus being negative, or *between the glasses,* it can only be made to operate on an image already formed.

In the year 1815, being then a student in the University of Edinburgh, I began my career as a reformer of microscopes, from reading the article "Telescope," in the Encyclopædia Britannica, written by Professor Robinson, and chiefly from the consideration of a passage in it, which I shall here quote.

"We have examined trigonometrically the progress of a

* Vide Chap. XIX. p. 191, and particularly p. 200, of the "Microscopic Cabinet." Every thing I have there said concerning the art of looking into the defects of microscopes and engiscopes applies to erecting eye-pieces, *and also to telescopes, with very little modificaton.* He that hath eyes to see, let him see for himself, and be made a dupe no longer, either by fine-spun theories or great authorities.

† The ordinary construction rather resembles an Huyghenian eye-piece reversed, or inverted, which, of course, utterly subverts the achromatism.

red and a violet ray, through many eye-pieces of Dollond's and Ramsden's best telescopes, and we have found in all of them that the colours are united on, or very near, the field-glass, so that we presume that a theory somewhat analogous to our's has directed the ingenious inventors. We meet with many made by other artists, and even some of theirs, where a considerable degree of colour remains, sometimes in the natural order, and often in the contrary order: this must happen in the hands of mere imitators, ignorant of principle. We presume that we have now made this principle sufficiently plain. Fig. 20, No. 2, represents the eye-piece of a very fine spy-glass, by Mr. Ramsden; the focal length of its object-glass is 8½ inches, with $1\frac{1}{10}$ of aperture, 2·05° of visible field, and 15·4 magnifying power; the distances and focal lengths are of their proper dimensions, but the apertures are a half larger, that the progress of a lateral pencil might be more distinctly drawn. The dimensions are as follows:—

Focal lengths, $Aa = 0{\cdot}775$, $Bb = 1{\cdot}025$, $Cc = 110$, $Dd = 0{\cdot}79$.
Distances, $AB = 1{\cdot}18$, $BC = 1{\cdot}83$, $CD = 1{\cdot}105$.

"*It is perfectly achromatic*, and the colours are united, not precisely at the lens (*C c*), but about 1-20th of an inch nearer the eye-glass.

"It is obvious that this combination of glasses may be used as a microscope, for if, instead of the image formed by the object-glass at F G, we substitute a small object illuminated from behind, as in compound microscopes, and if we draw the eye-piece a very small way from this object, the pencils of parallel rays emergent from the eye-glass D will become convergent to very distant points, and will there form an inverted and enlarged picture of the object, which may be viewed by a Huyghenian eye-piece, and we may thus get high magnifying powers without using very deep glasses. We tried the eye-piece of which we have given the dimensions in this way, and

found that it might be made to magnify 180 times with very great distinctness. When used as the magnifier of a solar microscope, it infinitely surpasses every thing we have ever seen. The picture formed by a solar microscope is generally so indistinct that it is fit only for amusing ladies; but with this magnifier it seemed perfectly sharp. We therefore recommend this to the artists, as a valuable article of their trade."

I caused that distinguished artist, Mr. Adie, of Edinburgh, to execute for me a microscope similar to that recommended by the Professor, on which no expense was spared;—it of course gave an erect image. I was not content with it, its construction being too complicated, and its length inconvenient; moreover, though its angle of aperture was no greater than that usually given to eye-pieces, its chromatic aberration forced itself occasionally on my unwilling conviction in a manner which I could not resist, in spite of my faith in analysis. I naturally, therefore, imputed this defect to Mr. Adie's imperfect execution, and set him to work afresh, to make another microscope, on the plan of an erecting eye-piece of the ordinary construction, gaining the different powers by the application of Huyghenian eye-pieces to the image formed by the two bottom glasses. I was very much pleased by the distinctness of this microscope, and so were all who examined it; still, however, it was not achromatic, so I set Mr. Adie down, at the time, for a bungler, who could not adjust the foci and intervals of the glasses in a proper manner, and determined to have the thing done effectually, if possible, by London artists, which resolution I executed afterwards. In the course of these experiments I found the utility of getting the power at the objective instead of the ocular end of the instrument, as a much sharper image was thereby obtained; I accordingly deepened what I shall call the object-glasses, as far as one-fourth of an inch focus, and obtained a very superior microscope, an account of which has already been laid before the public.

As to achromatism, however, I regret to state that the London workmen succeeded no better than Mr. Adie, though I thought a feeble compensation was produced sometimes when the curves of the two plano-convex lenses which composed the object-glass were turned towards each other in the manner they have been engraved. I moreover once thought that I had got a combination that was *achromatic upon opaque objects;* and being determined to leave nothing to be done by any man who should take up the subject after me, I resolved to apply to Mr. Tulley, of Islington, to have his opinion and advice on the subject. He soon convinced me of the impossibility of obtaining achromatism in any case where an image was to be formed from a real object otherwise than by the action of concaves of flint glass, and that my ignorance of the art of seeing the flaws and imperfections of optical instruments was the sole cause of my supposing I had ever obtained achromatism in any degree.

Now as my respect for truly exact science is not surpassed by that of any man, I must confess that all these circumstances created in my mind some doubts and misgivings as to the accuracy of Professor Robinson's statements and theories, not very much unlike what I have observed in farmers in the country, when unable to reconcile the actual state of the weather with the predictions of Moore's Almanack, in which their faith is altogether inflexible.

These theories of Professor Robinson seem to have been resuscitated by Professor Airy and Mr. Coddington. The work of the latter gentleman, "On the Refraction and Reflection of Light," contains the substance of Professor Airy's papers on these subjects; and whether it is considered as a work of originality, or as a compilation from the writings of our first opticians, it is admitted to be the best publication of the kind at present extant, whatever defects it may possess, and wants no feeble testimony of mine in its favour.

I presume, however, that the most staunch advocate for the

dignity of exact science, while he will insist on the vast superiority of its evidence over that afforded by the senses, will never contend that it is to run diametrically opposite to their testimony. I shall venture, though well aware of what I am doing, to impugn its infallibility, in the case of these theories of achromatism of Professor Robinson, Professor Airy, and Mr. Coddington, on the ground that *no artist is able to make an achromatic instrument according to them.* I shall oppose the said theories by what we call, in common language, *facts;* for I must state that when I view the subject theoretically I am utterly unable to detect the least flaw in them. It is not to be expected, indeed, that a poor sciolist like myself should be able to school men of such high mathematical acquirements as the aforesaid *savans;* the task must evidently be left to mathematicians whose calibre is still larger than theirs*. I have already partly expressed my own views concerning achromatism, and I shall endeavour now to expand them into the following propositions, which rest on the basis of the evidence of the eyes, or experience.

1. When achromatism is obtained by the adjustment of lenses to particular intervals, as in the case of the Huyghenian eye-piece, such achromatism is absolute and perfect, and not

* Analysis may, I conceive, be subject to the following defects :—

1st. It may be founded on correct principles, but false in its details.

2d. It may be founded on false principles, but correct according to them, and also in its details.

3d. These defects may be combined.

I should suppose the theories of achromatization I have impugned to be in the second predicament, and the false principle assumed, to be, that *the compensation for dispersion may take place any how, so that it is effected on the whole system*; and that the *double correction I insist upon is unnecessary*; and it must be confessed that, viewing the subject *à priori, purely in a theoretical manner*, nothing can be more consonant to right reason than *that one compensation should suffice, always supposing that it is possible to effect it on the whole, without giving a correction to the objective and ocular part separately*, which, however, does not happen to be the case.

like that effected by the combination of a concave lens of flint glass with a convex of plate or crown glass, which never effects a complete neutralization of the chromatic aberration, as is well known; therefore, if engiscopes and telescopes could be made by the adjustment of a system of lenses to particular intervals, their achromatism ought to be decidedly superior to that obtained by the action of concaves of flint glass, and equal to that of a reflecting instrument.

2. The only kind of achromatization produced by convex lenses, which is known in practice, is when two are adjusted to an interval equal to one half the sum of their focal distances, or thereabouts. These conditions are not rigorously necessary, as the lenses may be placed somewhat nearer than that. Moreover, the intervals seem to differ a little according as the eye-piece is adapted to an engiscope or to a telescope; at least if the power of the former is low, and the tube short.

3. Many modifications of this combination may be made,—as by doubling or tripling what are usually termed the eye and field glasses, so that the compensation for a double or triple eye-glass may be thrown upon a double or triple field-glass: also, there may or may not be an interval between the lenses composing the eye and field glasses: still, however, the mode of compensation is the same.

4. *In order to form a truly achromatic erecting eye-piece, or engiscope, there must be a compensation both in that part which erects and forms the image, and in that which views it; therefore no achromatic erecting eye-piece, or engiscope, can be made with so few as three lenses,* because either the objective or ocular part must inevitably be without compensation.

5. An erecting eye-piece, therefore, can only be made really achromatic, if we do not employ concaves of flint glass, by combining two Huyghenian eye-pieces, or some modification thereof, together, in such a way that one shall erect and form the image, while the other is made to view it. As to *the*

interval between them, or what may be termed the second and third glasses, if the eye-piece consists of four, it may be greatly varied—for example, from six to eighteen inches, and more—*without sensibly affecting the achromatism**; *the first and third intervals only requiring to be determined with precision.*

6. Such an eye-piece could only be used for viewing an image, and could never be employed as an engiscope, because it would have no external focus in front of the bottom glass; therefore, an achromatic engiscope can only have a double compensation in the same way as a telescope has it, of which latter instrument it is nearly a modification; and as it is exceedingly difficult to procure perfect flint glass lenses of large diameters for the object-glasses of telescopes, it is devoutly to be wished that, by the omnipotence of analysis, we may at length be enabled to construct them absolutely achromatic, of one kind of glass only, by adjusting a system of lenses to particular intervals; while with proper attention to the forms of the lenses, their spherical aberration *ought*, at least, to be reduced to insensible quantities, using only a small angle of aperture, though it could not, perhaps, be wholly removed.

Now, on comparing these propositions with those contained in Mr. Coddington's work, under the head of Achromatism, page 262 to 269, it will be seen how completely theory and practice contradict each other.

According to Mr. C.'s theories the following is a specimen

* Thus saith experience: behold what theory says,—supposing the first and third intervals, a and i, to be ascertained, and given to find the second, e, this will be represented *exactly*, *of course*, by the following singular expression (the four numbered fs being the foci of the four lenses in the eyepiece, namely, 3, 4, 4, 3, vide p. 266):—

$$e = \frac{\{2(a+1)-(f_1+f_4)\}\, f_2 f_3 - \{3ai+f_1 f_4-2(if_1+af_4)\}\ \{f_2+f_3\}}{3\,\{i(f_1+f_2)+a(f_3+f_4)\} - 4ai-2(f_1+f_2)(f_3+f_4}$$

If $a = 4 \quad i = 5$ then $e = \frac{72}{11} = 6.5454.$

of the dimensions of an achromatic erecting eye-piece, consisting of four glasses; *vide* pages 168 and 266.

	Inches.
Focal lengths	3 — 4 — 4 — 3.
Intervals	4 — 6 — 5·13.

when the axis of the incident pencil is parallel to that of the lenses: when it is inclined to them, the following variation in the intervals will occur, if I rightly understand Mr. C.:

4 — 6·558 — 5·43.

I suppose, with due submission to better men, an *achromatic* eye-piece *ought to be achromatic:* let any optician execute this; if it proves to be achromatic, I shall make the *amende honorable* to Messrs. C. & Co.

If the lenses in the aforesaid eye-piece have the best possible figures, as ascertained in p. 79, the spherical aberration will be reduced *so low as* 0.003; that of the single equivalent lens of the least aberration being 0·75. (*vide* 179.) I wish the makers of the achromatic object-glasses had in general the luck to reduce their aberration as low as this, with any large angle of aperture. I conceive that another false principle has been assumed by Messrs. C. and their colleagues, relative to the spherical aberration; viz. that, like the chromatic, it does not require a correction both in the ocular and objective part, but that the compensation for it can be effected *upon the whole any how.*

It will be a memorable instance of the fallability of analysis, even when conducted by minds of the very first order, if the said theories are found to be false and erroneous, as I am perfectly satisfied they are—"for by their fruits we may know them to be so." I have always found that good sound theories will produce instruments which satisfy the eye; and though it must be admitted that this organ is exceedingly coarse, and easily pleased in the generality of mankind, it is nevertheless, in many instances, capable of acquiring a refined and accurate taste in optical instruments, by a good education, just as it does in pictures and other works of art.

I once had the honour of looking through a telescope of the Gregorian form, but constructed with mirrors of glass, by the late Mr. Tulley, according to the theory of Professor Airy. Mr. T. had expended the whole of his skill upon the instrument, and had worked the said mirrors over and over again, a great number of times, till his patience was exhausted; yet the confusion in the vision produced was so great, that it was but just possible to recognize objects.

I think when such an artist as Mr. T. cannot bring a telescope something near to distinct vision, when working to the utmost of his ability by the theory laid down for him, it is not unjust to conclude that such a theory must be *rotten at the very core.* Can it be said that such sophistries are *useful* as serving to exercise the understanding? I should say that they can only serve to habituate it to fallacious hypotheses, unsound subtleties, and delusions of every description. We had better remain in the dark altogether, than be misled by such *ignes fatui.* If books cannot be written even on the exact sciences, without being full of errors, what is to become of those on other subjects—such as politics, medicine, religion, cosmography, &c. where men's passions are perpetually interfering to warp their judgments, and lead them astray from the truth? Such considerations certainly ought to teach the proudest philosopher a little true humility.

In the second volume of Mr. Hume's Essays, section 12, entitled "Of the Academical or Sceptical Philosophy," Part Second, there are some curious reasonings on the subject of mathematical demonstration, which the reader would do well to consult.

I may observe that Mr. Coddington has been at the pains of falsifying his own theories, practically at least, to the best of his abilities, by presenting to opticians a compound microscope, termed achromatic, which is constructed according to them. It is described in his treatise on the "Eye and Optical Instruments," pages 60 and 61, under the head of *Achromatic*

Object-Glass, and is represented in plate 13, figure 190. He has implicated articles 205 and 210 with the expressions in pages 261 and 263, in the Treatise on the "Refraction and Reflexion of Light," in the construction of this instrument; and if he had succeeded in making it achromatic, there would be good reason for asserting that it is unnecessary to correct the dispersion of its object-glass separately; since, if his theories were accurate, a much better and purer achromatism ought to be obtained by the simple adjustment of a system of lenses to proper intervals. I assert point blank that his instrument is as complete a failure as any thing of the sort I ever attempted myself. I have examined one of these instruments of the latest and most improved construction, (which, however, differed not materially from that described in the Treatise on Optical Instruments, except in having a double field-glass,) and can, I think, be positive that both *the chromatic and spherical aberration of the objective part was wholly untouched*, and that *the eye-piece, consisting of four glasses, was achromatic**. Nothing can surpass the beauty of the field of this microscope; but if I may be allowed the expression, not-

* I hope I shall be excused for quoting a part of a note to the first tract I wrote on the Amician reflecting engiscope; in which I have in a manner *described Mr. C.'s instrument beforehand*, as the said note was published in 1826, before his work and microscope were introduced to public notice :—

"I cannot here refrain from protesting against those preposterous accumulations of eye-glasses which we find in the best common compound microscopes (as they are called). It would appear that the worthy glaziers, who preside over the destinies of these unfortunate instruments, have not yet discovered the right end of a microscope from the wrong one; at least they have vented their rage for improvement entirely on the eye-piece; having first doubled the anterior eye-glass, then tripled it, and finally interposed a body-glass of long focus between the field-glass and object-glass (making the eye-piece to consist, in fact, of five lenses); they sit down contentded with their large flat field of view, and imagine they have arrived at the very extreme verge of perfection. The object-glass is allowed to remain a pitiful double convex lens, being, I suppose, either above or below their art."

withstanding its extent and flatness, nothing more can be made to grow in it than in that of any ordinary compound microscope having a well-figured object-glass of the same power and angular aperture, used with an Huyghenian eye-piece also of equal power with that applied to the instrument in question.

The dispersive and spherical error of small lenses is undoubtedly small, as I have frequently remarked, but it is not insensible, even with a very small aperture, to those who know how and where to look for it. Some persons see it at the first glance; others, only if it is pointed out to them; and some not at all, if it happens to contradict their hypothetical assumptions and preconceived opinions; for there is no blindness greater than that generated not in the organ of sight, but in the mind which receives its impressions. We are, indeed, so accustomed to tolerate aberration in microscopes, that it frequently is unable to stimulate our senses.

Now I shall not condescend to discuss the point whether it is right or not to correct the dispersion even of small lenses and object-glasses: but *how is it to be done by an achromatic eye-piece?* as in the case of Mr. C.'s microscope. If a man chooses to tell me that those little rainbows and fringes of colour which appear in objects viewed by chromatic instruments, are, in his opinion, highly ornamental, and not at all injurious to vision, I can only say I wish him a better taste.

If people like to eat dirt, they shall meet with no opposition from me: much good may it do them.

The only case, I think, in which colour can be said to be corrected by an eye-piece, is when an object-glass, over-corrected for colour, is made to act with a chromatic eye-piece, as I have, indeed, before stated: having once caused the object-glass of an engiscope to be over-corrected, because it was to act with an erecting eye-piece of the ordinary construction, the beneficial effect of this arrangement was very sensible, and it might either be said that the eye-piece corrected the object-glass, or the object-glass the eye-piece. I am of opinion that though it

would be highly advisable to get rid of the chromatic aberration of simple and compound magnifiers, it is not sufficient to produce any real detriment to vision, unless with exceedingly minute and delicate objects, beyond that of giving a *false colouring,* especially if *oblique light* is used. This, however, we soon learn to allow for; it is, moreover, considerably concealed by their spherical aberration.

As to the spherical aberration of object-glasses and metals, inasmuch as it is sensible to vision, I am persuaded, from reiterated experiments, that the power which an eye-piece possesses of modifying or altering it is exceedingly feeble, at all events. A case, however, in which I can be positive that it does actually correct it, is that of the Gregorian *telescope,* in which, if the primary metal is *very nearly* right in point of figure—for example, a little too much inclined to be spherical or parabolical—the error may be corrected by giving the secondary one an hyperbolical figure. Moreover, in the Cassagranian telescope, it is well known that the aberration of the two metals (supposing them to be both spherical) is equal to the difference between the aberration of the convex and the concave, which is a clear proof that an eye-piece may correct to a certain extent, *where a secondary image is formed,* (for I consider the small metals and eye-glasses of the Gregorian and Cassagranian telescopes in their combined action, as neither more nor less than eye-pieces*, which operate by forming a secondary image, like the erecting ones of common spy-glasses). I should, moreover, conceive that the same conditions would occur, if achromatic glasses of similar construction and effect, and, in equivalent states of correction, were substituted for the metals of the Gregorian and Cassagranian telescopes, and made to operate against each other on the same principle*. I have in vain endeavoured to find an in-

* An inverting eye-piece for either telescopes or engiscopes may be formed of a concave lens, in place of the two first glasses of an erecting

verting eye-piece *of the ordinary construction*, which would exert an influence over the state of spherical aberration of the object-glasses and metals of engiscopes, *when no secondary image was formed.* My way of judging was to form an artificial star by their unassisted operation as magnifiers in a solar opaque microscope, making the posterior conjugate focus to be of the same length as in an engiscope, that is, eight or nine inches; and having carefully examined the state of aberration in the picture, I then have attempted to modify it (when formed at the field-bar of an engiscope), by various eye-glasses, but so far as my eyes are capable of affording a criterion, I never succeeded in any degree: the image appeared as intractable as a picture formed by human hands, and remained inflexible both in its defects and excellencies, whatever they might be: the various eye-pieces I employed gave a better or worse field of view, were or were not achromatic, &c., as *regarded their own intrinsic operation:* for example, they might give the oblique pencil in a better or worse state; but if the said oblique pencil came in a confused or distorted state from the object-glass, I never could make them improve it. At the same time I think it proper to observe, that I never tried *thoroughly* the effect of positive over-corrected achromatic eye-pieces.

All these experiments, however, have convinced me that a compensation for spherical aberration cannot take place upon the totality of an erecting eye-piece or engiscope, unless both the objective and ocular part have a separate correction, for they cannot correct each other. I therefore believe that Messrs. C. and Co.'s nostrums for the cure of this evil are just as

one, combined with an Huyghenian eye-piece, which I consider an equivalent to the concave metal of a Cassagranian acting along with its proper eye-piece, and capable of exerting a similar action on the primary object, metal or glass; that is, of reducing its aberration in the ratio of the contrary aberration of the concave lens.

good as those for chromatic aberration.—Vide p. 168 and 179 of the *Treatise on the Refraction and Reflection of Light*.

I here give the construction of an erecting eye-piece or engiscope, which is both achromatic and aplanatic, to an aperture of about 27°, and having, moreover, a reasonable good correction of the oblique pencil.

Let there be two achromatic lenses of suitable focal length to give the required power, and let the anterior or first glass have its focus about half the length of the second: a stop may be placed between them in the solar focus of the first, to regulate its aperture, if necessary: to these let an Huyghenian eye-piece be applied at a convenient distance. It is not necessary that either of the lenses should be perfect in itself; they may be framed so as mutually to correct each other's aberrations, both spherical and chromatic. If they have their internal curves in contact, and are cemented together, there will be no sensible loss of light in this eye-piece beyond that in the ordinary ones; and in this case also the correction for the spherical aberration may take place in Mr. Lister's method, which will considerably facilitate their construction.

I have already stated that I consider the ordinary erecting eye-piece sufficiently perfect for practical purposes; but I think it would be a great improvement on spy-glasses if they could be shortened nearly one-half, so that they should be easily held and directed by the hand, when charged with a power of thirty or forty. I think an object-glass of two inches and a half, or three inches aperture, does as much upon terrestrial objects, at least *in the day-time*, as any other; the focal length of which is generally not less than thirty or thirty-six inches, which renders the glass too long to be easily used without a stand. If the focal length was reduced to fifteen inches, the angular aperture would thereby be doubled, and with it the defining power also (provided it could be perfectly executed). In this case the erecting eye-piece I have given would be indispen-

sable, for the colour of an ordinary one would become very sensible.

Trading opticians may not much relish my recommendations, but I say, and will maintain, that terrestrial telescopes will not have received their finishing touch, or have arrived at their *ne plus ultra* of perfection, until their secondary image is just as perfect as their first, and it can only be rendered so by being formed by regular achromatic glasses. Moreover, when we apply an erecting eye-piece to the object-glass of an engiscope, so as to obtain a low power, and for that end thrust it far into the body, so as to approach very near to the object-glass, (in which case what I shall call the posterior angle of aperture becomes considerable,) a truly achromatic construction is also highly requisite.

A positive inverting achromatic eye-piece for astronomical telescopes, or for engiscopes used with micrometers, may be made of two double achromatic glasses, having their convex lenses next the eye, with a certain interval between them, for the purpose of improving the oblique pencil. They may be either achromatic and aplanatic in themselves, or by mutual correction, and their foci may be varied at pleasure, provided that of the second or field-glass is not shorter than that of the first. I am sorry to say that I have not been able to procure any combination which gives so flat a field of view as I could wish, consistent with perfect distinctness. If it is thought worth while to obtain a large field at the expense of centrical perspicuity, we have only to reverse the position of the glasses, and that purpose will be accomplished.

It only remains for me to say somewhat about oblique pencils; they are very much mistaken who suppose that they have not received quite as much consideration as they deserve from those who have interested themselves of late in the improvement of the microscope. It is well known to every man practically acquainted with optics, and ought to be much better by those who know the science theoretically, that in all

constructions whatsoever there is *a perpetual system of gaining advantages in one direction, and losing them in another*, just as in mechanics,—what is gained in power is lost in time, &c. It is not permitted to man, assisted by the most powerful analysis, to combine together every advantage he may desire: he must content himself with what is attainable, according to the laws of the refraction and reflexion of light. I have ever found that all those constructions which give a very large angle of aperture, combined with great distinctness, invariably produce what is called a bad field of view; that is to say, the vision is only perfect in the centre. In refracting instruments a good deal may be done by combining several object-glasses together, more especially if they have intervals between them, (which, however, produce great inconvenience, by shortening the anterior conjugate focus, and thus precluding the use of high powers). As the action of metals is very simple in comparison to that of lenses, I shall give an illustration of the mischief occasioned by what is called improving the oblique pencil in the Amician reflecting microscope. It must be evident, that as the angular aperture is increased, the error of the oblique pencil must also be augmented, for it will come more and more oblique; now Mr. C. has actually recommended opticians to render the concave metals of the aforesaid instrument *spherical*, because in this case every pencil becomes equalized, and may be said to be equally bad or good, distinct or indistinct, throughout the whole field of view, though, so far as the objective part of the instrument is concerned, the whole instrument becomes utterly worthless, if this figure is adopted. They who work the metals of this instrument well know what infinite pains they have to get rid of this spherical figure, and to attain the true one*; and that when they have done so,

* I have known Mr. Cuthbert to have been *employed a whole week in getting rid of nothing but the spherical error* of one of his metals of 3-10ths of an inch focus and the same aperture, and not able to succeed at all in

the point is effected at the expense of a certain want of perspicuity about the edges of the field of view, which is altogether irremediable with low powers, which take in a large portion of the marginal part of the image.

If Gregorian and other telescopes, having a *large angular aperture,* are charged with a low power, the same defect is also very perceptible in them.

The Newtonian and Herschelian telescopes having very small angles of aperture, will admit of concave metals with spherical figures, because in this case the aberration occasioned by such a figure will be quite insensible. I do not, however, believe it possible to preserve a perfect spherical figure in metals having very small angles of aperture: for, in the process of polishing, it is sure to pass into the parabola at least, if it does not get beyond it, in spite of the utmost efforts of the workman. All that I ever examined are in the predicament of inclining to a hyperbolical figure, instead of a spherical one.

Of a piece with the performance of a spherical metal is that of a globular or bird's eye object-glass, which is considered to produce an excellent correction of the oblique pencils, because they come exactly like the centrical ones, which are utterly uncorrected, for the aberration of a sphere is to all outward demonstration much the same as that of an equi-convex lens, and requires as strong a concave to correct it.

When the omnipotence of analysis shall *point out some truly achromatic and aplanatic construction, which will give an oblique pencil as perfect as a centrical one,* then will the labours of mathematicians have assumed a proper direction. At present I am afraid they have been hallooing before they are out of the wood. I trust, however, that the time will

certain states of the weather, supposing always that a perfect figure was to be combined with a perfect polish.

come when the subject (which seems to me both useful and important) will be taken up in the right point of view, or it will be likely to remain a standing *opprobrium mathematicorum*.

It is quite plain that compound microscopes and erecting eye-pieces are only part and parcel of the subject of telescopes, and worthy of the same attention. Nothing which concerns the exact sciences can in my opinion be frivolous or unimportant: a mere subtlety or conundrum having the charm of exactitude about it, must always be respectable, although it may be of no apparent utility.

I shall leave it to others to judge how far the subject of microscopes is insignificant, or easily discussed; and I should recommend those who consider it theoretically, in future not to disdain to receive every assistance which experience and practical men can give them, before they embark in it "*out of sight*," like Pantagruel and his companions in quest of the oracle of the bottle; and to remember the Laputan tailor, who being too great a mathematician to avail himself of any of the practical implements of mensuration belonging to his trade here in Europe, and working entirely by analysis, always sent home his customers' clothes damnably ill made at all points. It was in vain that he swore, down their throats, that their clothes *must* be well made, and were so, for he could not err in his calculations, &c.; he was only answered by derision, slaps on the chops, and kicks on the breach.

If we examine into the amount of the obligations opticians and optical instruments have derived from the science of mathematics, we shall find them fewer and less onerous than we might expect. Sir I. Newton certainly preconceived the possibility of correcting the chromatic aberration of lenses by the opposite refraction of a concave medium of greater density; but this discovery would have been of small use, if the spherical aberration could not have been corrected by the

same means: which was an idea which does not seem to have struck him, but was excogitated by a practical man, the elder Dollond, who seems to have made excellent telescopes long before any theory was in existence sufficiently correct for an optician to work by.

The late Charles Tulley, (certainly one of the first opticians of his day) assured me, that he never could find any theory, English or foreign, by which a *really good telescope* could be made*; all the calculations of curves he ever saw being more or less inexact, *and requiring after correction by trial, before an instrument made according to them could be perfected.* The best he ever met with are those of Sir J. Herschel, but these are faulty, and have too much aberration in the concaves, which he was obliged to reduce before he could make a perfect instrument by them. To Sir J. however, we are much indebted for some excellent aplanatic combinations for eye-pieces and magnifiers, which seem to leave nothing to be wished for or desired.

The Huyghenian eye-piece, a most valuable invention, was partly the result of experiments; Huyghens having purposed only to correct the spherical aberration of an eye-piece by his combination, which was afterwards found to be capable of correcting the chromatic also.

It cannot be denied, moreover, that we have been favoured with many excellent theorems and recipes for correcting the distortion produced by lenses, and obtaining what is called a good flat field of view: this is a subject on which the mathematicians have been more successful than any other. To them we likewise are indebted for the knowledge of the value of the aberrations of lenses of different figures, according to the

* The article Telescope, in Rees's Cyclopædia, was written by Dr. Pearson, but the *materiel* was furnished by C. Tulley. It shews how telescopes actually *are* made, and may be perfectly relied on, by the artist.

refractive and dispersive powers of the substances of which they are made, &c.

We have seen what theory has done for us in the case of erecting eye-pieces and engiscopes, &c. With respect to achromatic object-glasses for diverging rays, Euler has recommended us to reverse those of a triple object-glass made on a small scale—a wretched expedient, which will never make a good instrument. Probably in the course of about another century, long after the said object-glasses have been perfected by practical men, some pompous analyst will arise, who will buckle on some sort of *semi*-exact theory to them.

C. R. G.

CHAP. VII.

ILLUSTRATIONS OF THE ALTERATIONS

PRODUCED IN THE VISION OF CERTAIN MICROSCOPIC OBJECTS, BY USING INSTRUMENTS HAVING VARIOUS ANGLES OF APERTURE, BUT A *FIXED POWER.*

Mr. J. Murray, of Albemarle-street, having, with the consent of Mr. Brande, allowed Mr. Pritchard the use of a plate formerly published in the 22d vol. of the Journal of the Royal Institution, with a paper of mine on Achromatic Objectives and Test Objects, I shall take advantage of the liberality and kindness of these gentlemen to present to the public a few illustrations of the said plate, as I have never written any thing on the subject of the present tract, except in the aforesaid paper. I must observe that when it was published, Achromatic objectives were quite in their infancy, the podura was unknown, and the diagonal lines on the brassica were undiscovered; nevertheless, with proper allowances on these points, the said plate will serve my purpose indifferently well.

As the subject is now pretty generally understood by the observers of the present day, I shall be brief in what I say, which must be understood as adapted to the calibre of the rising generation, and those readers who have not yet made microscopic science their study.

Fig. 1 is a very tolerable representation of an excellent and very beautiful test, a feather from the wing of Morpho Menelaüs, (being the first object in which I observed the very remarkable property of the lines as tests), as shewn by a triple object-glass of 2-10ths of an inch focus, and 1-10th of an inch of aperture, or $27\frac{1}{2}°$. The cross striæ are not so numerous as they appear, when the object is illuminated expressly for the purpose of shewing them, when, indeed, it appears like a piece of brick-work ; but in this case the longitudinal lines are rendered much fainter; therefore a kind of medium illumination was employed.

The seven circular discs are supposed to pourtray a small portion of the said scale, seen with an object-glass of half an inch aperture, and 9-10ths* of an inch focus, used with a negative eye-piece of 1-4th of an inch, and having five different circlets or stops applied to it, so as to cause its aperture to vary from 1-10th of an inch (the usual aperture given to a lens of that focus in the old compound microscopes) up to half an inch, by a gradual increase of the size of the perforation of the stop.

Disc No. 1, Aperture 1-10th.—The scale appears quite dark all over; not a vestige of its lines is visible; even its blue colour is scarcely perceptible.

No. 2, Aperture 3-20th.—Very little improvement; the colour is lighter, the blueish tint more apparent; we may contrive, by looking with all our might and main, to fancy we see some indications of lines, or rather scratches.

No. 26, Fig. IV.—Aperture 1-5th of an inch, colour lighter and brighter; traces of irregular scratches are now clearly perceptible here and there: peradventure we shall see what we shall see, by and by, as the Mussulmans say.

No. 28, Aperture 3-10ths of an inch.—Land begins to be

* Fig. 13 represents the curves of this object-glass, but of twice their real radius, for the sake of greater accuracy.

seen from the mast head: a practised eye will now recognise the nascent lines, but they seem like an aggregation of dots, and are interrupted and broken: the spaces between them are still very dark.

No. 3, Aperture 4-10ths of an inch.—The lines are at length resolved, but not fairly; they are very faint, and seem ragged, as if still composed of dots and points, but more closely conglomerated than before: the spaces between them are still far too dark.

No. 4, Aperture 5-10ths, or without a stop.—The lines are as much resolved as they can be by an object-glass of so long a focus. They now appear in their true character, that is, pretty fairly drawn as if by a pencil of deep black lead on tolerably white paper, or, more correctly speaking, by a pen with some blue pigment on light violet-coloured paper; for their bluish tint is now abundantly manifest.

No. 5, Aperture naked as before, but the object turned one quarter round, in order to permit the illumination to operate on the cross striæ, which now become perceptible, though as a *minimum visible*, being by no means shewn so strong as in the plate: if the observer should not have seen them before with a deeper object-glass, he might be expected to consider their existence very dubious.

Such are the effects of various apertures on the object in question, the power remaining the same. For the information of such as are but young in these matters, it behoves me to remark that, *with so small an aperture as* 27½°, *not one of the phenomena I have mentioned will be seen at all, unless the illumination is oblique.* Vide Figs. II. and III. shewing a plan and elevation of the relative situation of the object, and of the taper employed to shew it, when the illumination is conducted in a proper manner. If, however, the aperture is very large, and the object-glass deep, then the lines and cross striæ will be developed any how, or in spite of the most direct light which can be used, and this with a moderate power.

Figs. V. VI. VII. are examples of tests which are invisible with $27\frac{1}{2}°$ of aperture, even when assisted with the most favourable light, and the greatest amplifying power: the regular microscopist will probably recognise in them the *pieris brassicæ,* two specimens of feathers from the clothes moth, and the scales of the diamond beetle (which are supposed to be here shewn as transparent objects): the minimum of angular aperture they require is about $36\frac{1}{2}°$, consequently they can scarcely be shewn by any single object-glass.

Fig. V. is, of all other objects, that best adapted for a test, on account of its singular uniformity of structure. Mr. Pond, our late worthy astronomer royal, has noticed a remarkable feature in it, which is, that it is sure to be *invariably of the same length;* now I suppose if we were to collect all the leaves from any tree whatever, we should scarcely find two of them exactly of the same length, when subjected to strict micrometical measurement: and I think the same would hold good with respect to the scales of almost any other insect, and indeed to the other scales of the brassica also; I mean those not of the particular character here alluded to.

The effects of various apertures on the markings of this capital test are as follows* :—Up to $27\frac{1}{2}°$, either in glass or metal, nothing can be observed about it *with certainty;* its surface appearing so nearly uniform, that no one who saw it for the first time, and did not know there actually were lines or markings upon it, would suspect their existence, whatever power may be employed. Between $27\frac{1}{2}°$ and $36\frac{1}{2}°$ faint glim-

* In this, as in all other cases, I always suppose the power used to be equivalent to the manifestation of the lines or markings, that is, inasmuch as a certain power is necessary to render the human eye capable of discerning them; but the object of this paper is to impress on the mind of the reader *the effect of aperture*, or, what is the same thing under another name, *penetrating power as distinct from magnifying power;* which latter is no doubt able to accomplish a great deal, but never can supply the place of a *large visual* pencil of light, which, as it is the ultimate effect of a large aperture, is another term nearly synonymous with it.

merings of marks of some kind begin to manifest themselves; with 36½° lines of a ragged, broken, uneven contour, are plainly seen, as well as cross striæ: if the objective is a *metal* of good figure, a *few* oblique lines will also be developed.

If the aperture is above 36½°, and approaches to 55° *in glass*, (whether in achromatic engiscopes, compound magnifiers, or simple ones), the lines will be more strongly made out, but will appear to consist of an aggregation of points: the cross striæ will be shown closely packed together all over the scale, and occasionally a few oblique lines will be *faintly* exhibited: if the aperture is as much as 60° or 70°, and the object-glass or magnifier at the same time very deep, nothing but a tissue of dots and points will appear, occupying the site of the longitudinal lines.

The effect of 55½° of aperture in a well-figured *metal* of 3-10ths focus, is very different: the lines and cross striæ will not in this case be resolved into dots or points, but will appear in, what I suppose to be, their proper character; and the two sets of diagonal lines will be shewn with a force and effect which will leave no doubt of their existence in the mind of a candid observer; the various lines, the longitudinal, the cross striæ, and the two sets of diagonals, being all observable, *successively*, by a slight change of the illumination, though we can rarely see two of the systems well at the same instant.

Being aware that the invidious would be likely to assert that the scales and feathers of insects were objects *sui generis*, and that it was of little consequence whether microscopes and engiscopes, devoted to the examination of other objects, would shew them or not, I from the beginning associated others with them, which no naturalist can pretend to assert should not be properly exhibited by all instruments fit for philosophical investigation of the minutiæ of nature. Accordingly, fig. 9 is a bat's hair shewn as an *opaque* object; fig. 10 (*a*), a large mouse hair, shewn as an *opaque* object also; and fig. 12, a

fly's foot; (*b*) fig. 10 is a small mouse hair, seen as a transparent object; fig. 8, the fragment of a leaf of the species of the moss hypnum.

Now none of these can have their minutiæ properly shewn without an aperture of 27½° *perfectly free from aberration**; and indeed, if the aperture is much greater, it will be found vastly acceptable, by facilitating vision. The bat's hair sufficiently explains itself; the large mouse hair has pits in it, just like the interior of a tea-cup, and which ought to be made out as distinctly: the small mouse hair (which is shewn by transmitted light) has fine longitudinal lines connecting its joints, which are the most difficult parts to develop. The hypnum should have all its component lozenges distinctly made out: object-glasses will frequently shew the Meneläus, and other lined objects of a similar class, and yet not define these: reflectors are apt to boggle at them. I may observe that Mr. Pond has discovered, (by using object-glasses and lenses of *very large aperture* and high power), that what I have termed the lozenges of the hypnum are, in fact, hexagons, having two opposite sides longer than the rest.

The fly's foot has the following notabilia about it:—the lines on the hairs about the ancle at (*b b b b b*); the scales on the pastern (*c c*); the grooves on its claws (*a*); the white points (*d d*) on the soles of its feet, and the fine fringe (*e e*), which surrounds them.

As to the said drawing of the fly's foot, it is a wretched affair; because the said foot was fastened to a black cylinder with gum, and thereby sadly distorted, one of the claws being entirely sunk and invisible in the gum, yet it happens to shew all the minutiæ pretty well. Copper-plate engraving is not at all adapted to exhibit this object well; a wood-cut does much

* This is a condition which I always suppose associated with aperture; as without it the mere opening out of a glass to a large diameter does as much harm as good.

better: and in the succeeding volume (the first of the new Series of the Journal of the Royal Institution), the reader will see one which gives a better idea of it.*

Now, in order to illustrate my position about the value of aperture, in exhibiting so very ordinary an object—the foot of a common blue-bottle fly—I hope it will not give offence if I refer the reader to the celebrated Bauer's drawings of the same object, in the Transactions of the Royal Society for 1816, p. 146, belonging to a paper, entitled, "Some Account of the Feet of Animals whose progressive motion can be carried on in opposition to Gravity," by Sir E. Home; in which all the minutiæ I have detailed *are totally passed over*. In the wide world, where shall we find an artist who can delineate objects so beautifully and so faithfully as Bauer? What is the reason, then, that he has committed so many sins of omission in this particular instance? I answer, that the fault lay not with him, but with the instrument he used, which, though it might be one of the best which could be procured at the time he made the drawings in question (at which period achromatic objectives were unknown), wanted the penetrating power or aperture necessary to develop this object. Mr. B. drew exactly what he could see with certainty—nothing more or less, as was his bounden duty.

Why have I, in my drawings of the wheel animalcule, in the

* I have forgot which of the fly's feet I have drawn; they differ considerably from each other; but I think this was a hind foot. I have been told more than once that my drawing is unfaithful, because all the *minutiæ* I have represented *can never be seen at once*, as in the drawing. What could I do? This object requires a power of 1-30th inch for its development: as its surface is quite uneven, only a point can be in focus at once, or perfectly exhibited. Ought I to have made twenty drawings of it to shew it just as it appeared at every different adjustment of the focus of the instrument? The true way to draw it is surely to represent it just as it would have appeared had it been of the size of the drawing, and seen as ordinary objects are—a cat's paw, for example; *i. e.* without any instrument, or magnifying power at all.

"Cabinet," omitted to give the eyes, and a variety of other minutiæ since discovered in that animal? I answer, I had nothing but uncombined triple object-glasses to use, which, though they were fine things in their day, were utterly inferior in penetrating power to the triple systems of double achromatics now made. I drew just what I could see, nothing more or less.

To what are we to attribute the astounding discoveries of Professor Von Ehrenberg, in the organization of the Infusoria, in comparison with which all other microscopic revelations seem to shrink into insignificance, even those of Leeuwenhoek (supposing them to be correct)?

That creatures *generated without any primitive organic substance,* and so minute that we were formerly content to see little more than their outline, and many of which were supposed to be as simple in their structure as an hydatid, should be found to possess all the essential organs of the larger animals, and to be as perfect in their kind—to have the details of their whole anatomical structure laid open to us in so satisfactory a manner that we cannot entertain a doubt of their accuracy*—must be allowed to reflect eternal honour on the modern improvements on engiscopes; no less than on the skill, perseverance, and *profound* talent for microscopical and anatomical investigation, possessed by him who wielded their energies. Professor Von E. could not, I think (had he possessed no better tools to work with than the old microscopes), have succeeded in unravelling the construction of the Infusoria, however great the resources of his splendid genius may be: a good workman, it is said, never quarrels with his tools; but the subjects he had to work upon are totally invisible with in-

* *Vide* Organization, in der Richtung des Kleinsten Raumes. Dritter Beitrag. Von C. G. Ehrenberg: Berlin, 1834. Also, the Edinburgh New Philosophical Journal, for January 1836, p. 42.

struments which do not possess enormous *penetrating* power, combined with the requisite amplification ; therefore, when we compare the illustrious Professor's drawings of the Infusoria with those of the same objects by Müller and the earlier ob servers, we are presented with a very fair illustration (making an allowance for the effects of colouring matter introduced in the systems of the animalcules) of the difference in vision produced *by large and small apertures ;* for in the article of *magnifying power,* the old instruments were quite equal to those of the present day.

C. R. G.

CHAPTER VIII.

ON THE CONSTRUCTION AND MANAGEMENT OF SOLAR AND OXY-HYDROGEN GAS MICROSCOPES, &c.*

The opinions respecting the apparent magnitude of bodies seen through optical instruments in general, are so conflicting, and often deviate so widely from the truth, that it is of great importance to be enabled to have recourse to any plan by which their admeasurements can be accurately determined. With the solar and gas microscopes, whose several properties I propose to consider, a method of doing this is readily supplied: for, by the contrivance of a screen, upon which the images or pictures of objects are formed, their superficial contents may be ascertained with the same precision as if they were the real objects themselves. In this respect, therefore, we have a remedy against those optical deceptions in the appearance of things, which frequently occasion no inconsiderable inconvenience to an observer. Nor is this facility of com-

* This Tract was originally intended to have preceded Chap. IV.; but it was found more convenient to place Dr. Goring's papers together, as his proofs had to be sent to North Devon for correction, and the engraver had not then completed the wood-cuts.

puting correctly how much an object is magnified the only advantage peculiar to them; for, with these and similar instruments, a number of persons can view a living object at the same instant of time, and remark upon its particular organization, functions, and habits, with great exactness, and satisfaction to themselves and to one another. The force of this observation will be sufficiently manifest, if we reflect that most diminutive living objects are constantly in motion, and that with the table miscroscope or engiscope, before a second observer can possibly note any peculiarity mentioned by the first, the creature will most probably have changed its position, and the part to which his attention was especially directed may be entirely concealed from his view. Persons of weak sight, who are unaccustomed to look through a table microscope, (for it does not occur to those who are well versed in these matters,) sometimes experience a little fatigue from the eye being intently fixed for any considerable time upon the same object, and subjected to the stimulating action of the intense light often thrown upon it for its illumination. The inconvenience arising from this does not apply to the solar and gas microscopes, the absence of which may therefore be enumerated very fairly among the advantages peculiar to them.

For the invention of the solar microscope we stand indebted to the good genius of Dr. Leiberkhun, who, about the year 1738, contrived an apparatus, by means of which a distinct resemblance of a magnified object, strongly illuminated by the condensed rays of the sun, (hence its denomination *solar microscope,*) was thrown upon a white screen, and rendered visible to any number of persons conveniently placed in a darkened room. To this gentleman's ingenuity we owe the valuable application, also, of the concave silver speculum, for concentrating the light upon opaque objects viewed through the table engiscope, as well as other improvements in that instrument. About the year 1774, Benjamin Martin published his description of the solar microscope, and its use in examining

opaque objects; subsequent to which, it underwent various skilful alterations in the hands of Messrs. Cuff and Adams, the latter of whom has given us a very minute account of the instrument, with drawings, in his quarto work on the Microscope, published in the year 1787,—omitting, however, it may be remarked, every particular respecting its optical construction. Since that time it has remained, until lately, quite stationary; and no practical work whatever has been written upon the subject.

In all the solar microscopes hitherto described, the optical part consists of a simple convex lens placed between the object (at a little more than its sidereal focal distance from it) and the screen upon which the image is designed to be thrown: hence it necessarily follows that they all have a considerable quantity of aberration, arising both from the figure of the lens, and the chromatic dispersion of the light. The former of these defects Dr. Robison in a great degree remedied, by substituting Ramsden's eye-piece in the place of the common lens; and Dr. Goring, by the application of achromatic lenses to the instrument, may be said to have effectually corrected them both*.

The oxy-hydrogen microscope, so attractingly exhibited in the present day, and unquestionably meriting all the encouragement that can possibly be bestowed upon it by the promoters of rational instruction, may be defined to be a mere modification of the solar, adapted to receive, and employ to the greatest advantage, the rays of an artificial light diverging from a central point, instead of the parallel rays from the sun. In the year 1824, Dr. Birkbeck delivered two lectures on optical instruments at the London Mechanics' Institution; in one of which he took occasion to delineate on a screen, by means of

* Mr. Benjamin Martin mentions in his works the adaptation of achromatic lenses to the solar microscope; but not being acquainted with the value of angular aperture, he only gave them the same as was usual with common lenses; hence they were laid aside as no better than the latter, and may justly be said to be re-invented.

a large magic lantern, representations of magnified objects intensely illuminated by the light emitted during the combustion of lime by hydrogen and oxygen gases*, and to indicate the practicability of applying successfully this method of illumination to the microscope. I would not omit, however, to mention, that, about the same time, Mr. Woodward instituted some experiments with the phantasmagoria, where the light was obtained in the same way†. In the interval between that and the present time, various amateurs and artists have studiously exercised their talents in perfecting the several parts of the instrument, which, like the solar, assumes its name from the source whence the light requisite to its action is derived.

In the present treatise I intend to lay before the reader a practical illustration of the construction of both the above-mentioned instruments, commencing with such parts of them as are common to the two, and then treating of those which are peculiar to each,—remarking also, as I proceed, on the various improvements they have recently undergone, and concluding with such instructions for the management of them as, I trust, will tend to remove those difficulties which have hitherto obstructed their being brought into more frequent use.

METHOD OF ASCERTAINING THE MAGNIFYING POWERS OF SOLAR AND GAS MICROSCOPES.

In all cases where the real dimensions of any object to be viewed with these instruments *is known*, the magnifying power may be readily computed, by simply measuring the length or breadth of the image or picture formed on the screen, and dividing them by the length or breadth of the object itself. Thus, for instance, suppose you had an object whose real length was the tenth of an inch, and whose image on the screen measured five feet in length, or sixty inches, the lineal magnifying power

* Mr. Cooper assisted Dr. Birkbeck in this experiment.

† Lieut. Drummond has ingeniously applied this light to Light-Houses and to Geodætical operations; *Phil. Trans.* for 1830, p. 383. See also the same work for 1826, p. 324.

of the instrument would be 60 multiplied by 10, or 600. But since the object has been magnified to the same extent in breadth as well as in length, the superficial magnifying power will be six hundred times six hundred, or 360,000; or, in other words, it would require 360,000 of the original objects to cover its magnified image. Some ingenious persons, whose design I suppose it is to astonish the world, carry their estimate to a much larger extent than this, and give to these instruments the marvellous power of exhibiting the solid as well as the superficial magnified representation of an object; but as it is clear that the superficies alone, without any portion of the thickness of the object, can be delineated on the screen, the superficial magnitude must suffice. The solid content is known (but cannot be seen) by multiplying the superficies by the diameter or lineal magnification. Another mode of determining the magnifying power is to measure the *distance* of the screen from the lens of the instrument, and divide that by the distance of the object from the lens. Thus—suppose the screen to be placed twelve feet distant from the lens, and the object one inch from it; divide twelve feet by one inch, and the quotient is 144, the lineal magnifying power of the instrument: consequently, the superficial magnifying power will be the square of 144, or 20,736. This result will not be accurately true, although sufficiently so for ordinary purposes: for in practice it is a point of difficulty to determine the *focal centre* of a lens from which the measurements ought to be taken, inasmuch as the thickness, form, and position (even of a single lens) must be considered, before the acting focal length can be strictly ascertained. In a combination of lenses, the matter of course becomes much more complex. I recommend, therefore, adopting the first method, and throwing the image of a micrometer upon the screen. In all cases where the magnifying power is not great, a disc with a circular aperture of known dimension, placed as an object, will readily determine its extent.

THE SCREEN.

The next thing in common, connected with the two instruments, is the Screen, upon which the image of the objects is displayed. In constructing this, every care should be taken to render its surface as smooth, white, and opaque, as it can be made; the chief consideration being, that it should reflect the greatest possible quantity of light, and absorb the least. The material usually selected for the purpose is a sheet of canvass properly stretched upon a frame, and painted with two or three coats of white paint; in doing which, some attention is required to smooth the surface between each layer with pumice-stone, or any other suitable substance, so that, when finished, it may be as plane and free from prominences or cavities as pains can form it. It is scarcely necessary to mention, that the purest white lead should be obtained, inasmuch as the brilliancy and perfectness of the picture will greatly depend upon the whiteness, and the sharpness of its outline upon the smoothness of the screen.

A screen of a superior kind may be produced by spreading a thin coat of plaster of Paris upon the flattened surface of a well-constructed wall. This, of course, will be a fixture; nor do I know that the last material can be used conveniently in any other way, unless on a small scale, when it may be attached to a moveable board or frame. The form of the screen will be regulated chiefly by the height and size of the room, and in some degree by the nature of the exhibition; but, in all cases where a circular one of sufficient dimensions can be contrived, it will succeed the best: it must be situated at right angles to the axis of the instrument. I may remark also, that, with the exception of the screen, the whole interior of the apartment should be made as black and sombre as possible, in order to produce a good effect.

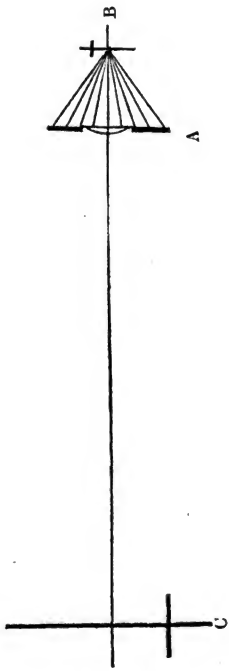
The position of the screen with regard to the instrument is of considerable importance; for if its centre is not placed opposite the axis of the instrument, and its surface in a plane every way at right angles to it, the picture will be a distorted representation of the object, its parts being magnified differently, according to their distance from the instrument.

CONSTRUCTION.

The optical construction of the solar and gas microscopes may be divided into two distinct parts: First, that which is necessary for magnifying the object, and depicting its image on the screen—which is, strictly speaking, the microscopic part; and, secondly, that by which the light is condensed upon the object—which may be termed the illuminating part. The microscopic part *may be* the same in both these instruments, and, by a suitable arrangement in the mounting, in the Table Engiscope also; but the illuminating part must of necessity be different. Pursuing the order, therefore, adopted at the commencement, I shall first describe that which is, or may be rendered, common to both—the microscopic part.

If we take a common convex lens, as shewn at A (Fig. 1), and place an object strongly illuminated at B, so that an image of it may be projected at C, that image of it will be an inverted magnified representation of the object. By a little consideration it will be evident, that all that portion of the light emanating from B, which conduces to form the picture at C, must pass through the aperture of the lens A,—the surplus rays, as indicated by the figure, being entirely obstructed and cut off. Now, in proportion as the picture C is enlarged, the available portion of the light will be spread over a larger surface, and consequently the picture will be more and more diluted. To remedy this defect, it would seem that you have only to extend the aperture of the lens by substituting one of

FIG. 1.



greater diameter, which shall transmit an additional quantity of light; but, by doing this, the following evils will arise:—

I. The aberration occasioned by the spherical figure of the lens will be greatly increased, and the image will be less defined.

II. The dispersion arising from the unequal refrangibility of the light will produce a strong colouring throughout the image.

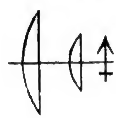
III. The aberration of the oblique pencils will cause indistinctness and colour around the edges of the field of view.

IV. The image being formed in a caustic, and not in a plane, it will not be distinct in all its parts on a flat screen, with the same adjustment of the instrument.

I shall now consider how these defects are to be obviated, taking them separately in the order I have noticed them.

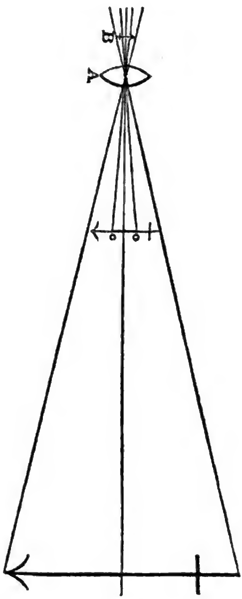
1. The first defect arising from the aberration occasioned by the form of the lens may be lessened by employing, in the place of a common convex lens, another of such a substance and form as shall cause the least aberration. To determine this, you must first ascertain the refractive power of the glass or gem of which the lens is to be made, and the distance at which the screen is to be placed from it; for it may be correct enough at one distance, but will not be equally so at another. It may be mentioned here, that, with ordinary glass, the form in most cases should be a plano-convex; the flat side being placed towards the object. But since the aperture in a single lens of the best figure cannot be greatly enlarged, it has been found expedient to have recourse to a combination of lenses. The most efficient combination I have met with for practical uses is a modification of Ramsden's eye-piece, before alluded to. When this is employed for high powers, it becomes of course the doublet of Dr. Wollaston, as described in the Microscopic Cabinet, p. 162. This combination, indeed, if properly executed, is the most efficacious that has hitherto been used for deep powers in the gas microscope. The form of the lenses and their arrangement is shewn at Fig. II. For further particulars respecting spherical aberration, see Microscopic Cabinet, p. 175, § 4, and p. 197.

Fig. 2.



II. The second defect, *chromatic dispersion*, arising from the unequal refrangibility of the light, may be remedied, as before mentioned, by substituting in place of a single lens an achromatic combination of lenses, which may be so formed as to obviate spherical aberration also. In the solar microscope, this combination has been used with considerable advantage; and there can be little doubt, that, for all scientific purposes where the utmost definition and correctness are required, it is by far the most perfect construction of any that has been hitherto discovered. It might probably be inferred from what has been said, that an achromatic object-glass completely rectified for a table engiscope would of necessity be adapted

FIG. III.



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for the solar; and so it would, as far as the two instruments correspond: but since the *angle of the field of view* in the former is generally much less than that in the latter, an achromatic object-glass suitable to the one *may be* wholly unfit for the other, and thus be found quite defective. For instance, let A (Fig. III.) be the object-glass, B the object, and *c c* the diameter of the *field-bar* of a table engiscope: now it is evident, that so much only of the object can be seen in the engiscope as occupies the space *c c:* but the illuminated disc, or field of view, on the screen of a solar microscope, should subtend a larger angle than that subtended by *c c,* viz. that under G G: all the marginal rays, therefore, beyond *c c* may pass uncorrected, and consequently may produce a distorted, coloured, and undefined picture.

It may be remarked here, that the field-bar of a table engiscope generally subtends an angle of from five to ten degrees, and seldom or ever exceeds fifteen; whilst the solar and gas microscopes should admit of an angle of nearly thirty degrees; indeed, I have seen some which subtended 45°. As, therefore, the area of the field of view in both instruments varies as the square of their diameters, in the most favourable case the latter will be four times the extent of the former.

The construction of achromatic object-glasses having been amply treated of in our other works, it would be improper to repeat it here: there are, however, a few observations connected with them that suggest themselves, which, if completely carried into effect, would probably render the solar microscope the most valuable instrument which the naturalist can possess, enabling him to obtain larger angles of aperture, and greater space between the object and magnifiers,—the first giving increased means of penetrating into the structure of bodies, and the latter affording practical facilities in the admission of objects, the want of which renders the best reflecting microscopes useless for the examination of a numerous class of objects.—First, then, the posterior focal distance of the object-glass in

a solar microscope being longer than in an engiscope, enables us with it to obtain a larger angular aperture without any augmentation of its real aperture, while it is now well ascertained that, in proportion as we reduce the length of the body, (that is, shorten the posterior focus of the object-glass or distance A *c*, Fig. III.) we must reduce its aperture to obtain all the necessary corrections. Thus, for example, suppose we have an inch-triple achromatic object-glass, and employ it with a body ten inches long, we may obtain an angle of aperture of 18°; but if we shorten down the body to five inches, then, to obtain the requisite corrections, it will be necessary to reduce its aperture to about 14°. Hence, in solar microscopes, where we have the posterior focus elongated twenty or thirty times, it is probable that a much larger angle of aperture might be obtained; and thus, with an object-glass of no shorter focal length than one quarter of an inch, we might probably obtain an aperture sufficient to penetrate into the structure of every object we are now acquainted with.

I should not omit to notice, that when the bodies with deep object-glasses, say one-tenth of an inch focus, are reduced one-half, their angular aperture remains nearly the same; and the reason is obvious. In the case of the inch object-glass we reduce the proportion between its anterior and posterior foci as low as one to five; but, with the same reduction of body and the one-tenth object-glass, the proportion remains as one to fifty.

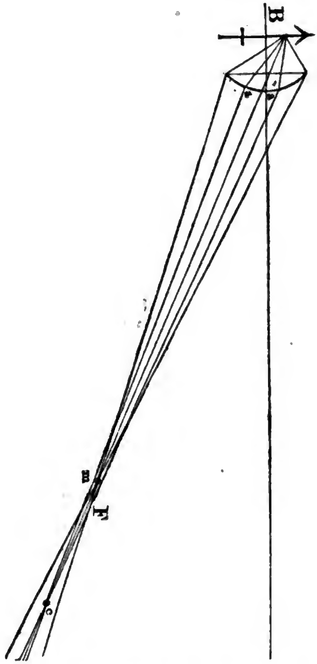
I may remark, as a caution to those who fit up solar microscopes with achromatics, that the lenses must not be cemented, as they may in use be soon spoiled by the heat of the sun.

The practical rules for determining how far any combination of lenses is free from chromatic dispersion, are amply detailed in the Microscopic Cabinet, p. 200: see also Test Objects, chap 16.

III. The third defect, the aberration of the oblique pencils of rays, will be better explained by referring to Fig. IV., where B represents the object: from any point B not in the

axis of the lens, let a pencil of rays be incident upon the lens, and refracted to form an image at that point at F. From the

Fig. IV.

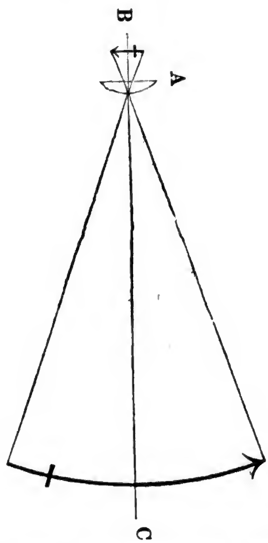


spherical figure of the lens, the extreme or marginal rays of the pencil will undergo greater refraction than those represented by *a a*, nearly coinciding with the axis of the pencil, and will meet at *m*, the focus of marginal rays, whilst those near the axis of the pencil will proceed on to *c*, the focus of central rays; consequently, an indistinct circular representation of the point B will be found between *b* and *m*, the longi-

tudinal aberration of the oblique pencil. A similar effect will take place in all the other pencils passing through the lens from every point of the object B.

This aberration of the oblique pencils may be corrected by a proper form and combination in the achromatic object-glass; for although it is a manifest and visible error, it would not be advisable, in practice, to construct a form exclusively to remedy it, unless, indeed, when very low powers only are to be employed; in which case it can in a great degree be done by a right adjustment as to distance of the lenses shewn at Fig. II., and giving their surfaces the necessary curvature, so that the defect will be imperceptible.

Fig. V.



IV. The last defect I have to notice, will also be better understood by a direct reference to Fig. V., where A is the lens,

B the object, and C its image. As the several portions of the object B are at unequal distances from the centre of the lens A, the image C, instead of being formed on a plain surface, will assume a curve. as represented at C. To remedy this, it is only necessary that the screen should be constructed of a corresponding curvature; but, in practice on a large scale, this will be extremely difficult: moreover, with every change of magnifying power, or variation of distance between the lens and the screen, a new curve for the latter would be required. By adopting the converse method, however, and mounting the object between two surfaces of the proper curvature, such as watch-glasses, an image will be seen equally distinct throughout the entire field: thin sections of vegetables, specimens of gauze, lace, and other flexible substances, are viewed extremely well when mounted in this way, especially when the angle of the field of view exceeds 30 degrees; although it is not advisable to employ a larger angle if it can be avoided.

Mr. Coddington, who appears to have been the first person to investigate this error in microscopes, has succeeded to a great extent in correcting it, by substituting spheres of glass in place of other lenses. This contrivance is shewn at Fig. VI., where the aperture of the sphere is defined by a groove cut about its equatorial parts.

Fig. VI.

"The only point of consequence is," says Mr. Coddington, "that the rays which pass through this magnifier should traverse both the refracting surfaces without any obliquity, by which means the whole field of view is equally distinct." The two refracting surfaces here alluded to are, of course, portions

of the same sphere, and, if continued, would meet. I have made this remark simply because, in all the Coddington lenses that I have examined, there is a great fault in the making of them: few, if any, do form perfect spheres, if thus continued. Mr. Coddington has recommended me to make these spheres of rock crystal;* and Sir D. Brewster considers that they would be quite perfect, if composed of garnet, and used in homogeneous light.

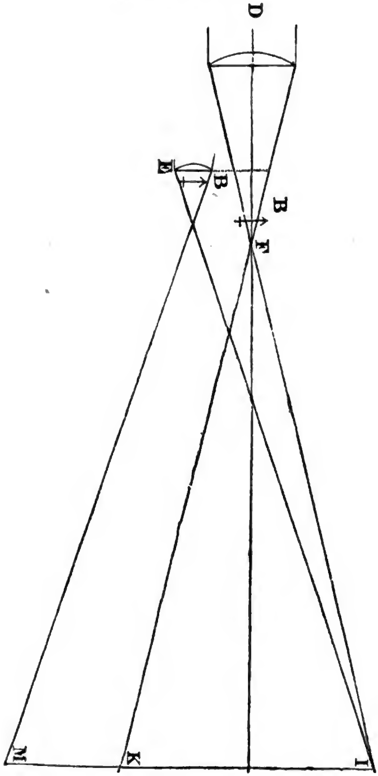
FOCAL LENGTH OF MAGNIFIERS USED IN SOLAR AND GAS MICROSCOPES.

The range of magnifiers suitable for either of these instruments depends upon the dimensions and arrangement of their illuminating apparatus. In the larger ones, which are by far the most instructive and amusing, and best adapted for public exhibitions, a great extent of surface can be intensely illuminated, and therefore very feeble magnifiers can be employed; the lowest having a sidereal focal length of about three inches, and thence proceeding upwards to a quarter of an inch. If they are much shorter than a quarter of an inch, unless the field of view be small, and the instrument very accurately constructed in every part, the image on the screen will be little more than a gigantic coloured shadow of the object. Indeed I may safely assert, with respect to the gas microscope at least, that, with its most extravagant magnifying powers, none of the minutiæ of an object have been displayed which could not be seen through a simple microscope with a single lens or doublet of a quarter of an inch sidereal focus. With the solar, a magnifier as high as the sixteenth of an inch may be advantageously employed, although half that power will be

* I find, with this medium, that a slight obliquity produces double refraction.

found amply sufficient for most scientific purposes. I am aware that, in Germany, the polygastric sacs, or stomachs, in the smallest genus of animalcules, the Monads, are said to have been rendered distinctly visible with the solar microscope; to effect which, a power of the sixteenth of an inch, if not a deeper one, would certainly be required. The most splendid

Fig. VII.



solar that has ever been produced in this country had a set of achromatic lenses, whose foci ranged from an inch and a half to two-tenths of an inch; but, in some that I have made with achromatics of two inches focus, even their superiority over common lenses was decidedly manifest; and, as the powers become deeper, the advantages to be derived from the achromatic construction increase in a high ratio.

ILLUMINATION FOR SOLAR MICROSCOPES.

Transparent Objects.

Fig. VII. will illustrate the construction of the illuminating apparatus of a solar microscope. D is the large convex lens for condensing the parallel rays of the sun; F the sidereal focus of the lens D. The condensed rays of light, after crossing at the point F, will diverge towards the screen I K M, and may be supposed to occupy the space I K. Now, if the instrument be so constructed as to require the object to be placed at the point B, it is evident that the central portion of the object through which the condensed rays must pass, will be powerfully illuminated. But if the microscopic part of the instrument, viz. the magnifier, will take in a larger portion of the object than is thus illuminated by the lens D, it is evident that we shall not obtain so extensive a field of view as the microscopic part of the instrument will admit of. To supply this deficiency, an additional lens E, as shown in the drawing beneath, may be introduced at the dotted line, the effect of which will be to make the rays converge to a point much nearer to the lens D than is its sidereal focus F, and consequently to increase the angle of divergence I F K,—thereby occasioning the rays to illuminate an enlarged space, I M on the screen, by which means the field of view is greatly extended. If the object B be now placed close to the *field lens* E, every portion of it will be illuminated. As, however, different sized objects require differ-

ent magnifying powers to display them properly, it is necessary, in like manner, that the field lenses be suitable to the powers employed.*

Since it is necessary that the sun's rays should pass *directly* through the lens, in order to form a proper disc upon the screen, it will appear evident, either that the axis of the condenser D must be directed towards the sun, or that a plane mirror be so placed behind D as to reflect those rays along its axis. The latter method is usually adopted, as being by far more convenient and simpler than to be continually changing the position of the instrument and of the screen. It is important that the mirror be made as perfect as possible, lest a considerable portion of the light be absorbed, or otherwise injured. For this purpose we generally employ a silvered looking-glass, (a speculum of sufficient size being too costly,) which should be of *thin* Dutch plate-glass, as free from colour as it can be procured: if it be not thin, the images of the sun reflected from each of its surfaces will be so far separated as to be visible on the screen, projecting a double image of the object, the one overlapping the other.

The intensity of the light condensed upon the object by the lens D, Fig. VII., (if there were no light lost in reflection from the mirror, or from the surfaces of the condenser, and none absorbed in passing through it,) will be in the proportion of the squares of their respective diameters. Thus, if the diameter of the condenser were six times that of the object, the latter would be illuminated by a light 36 times as intense as that direct from the sun. If it were wished therefore, to magnify, the same number of times, two objects of unequal size, which should be equally illuminated, it is clear you would not require so large a condenser for the smaller object as for the other:

* In all solar microscopes, the construction requires the illuminating rays from the object to be converging; but it is probable, if they were diverging, that a superior definition would be obtained, as is found to be the case with delicate objects under an engiscope.

hence, for a solar intended to exhibit large objects, where a considerable surface of condensed light is absolutely necessary, or where very high magnifying powers are to be used, which greatly extend the disc over which the light is to be spread, a condenser of comparatively large diameter will be required.

The diameters of condensers for solar microscopes vary from an inch and a half to about six or seven inches,—those of four or five inches being the most convenient and generally useful. If they are much smaller than that, they will not sufficiently illuminate large objects, and are consequently suited only for a limited class of them; and when they exceed seven or eight inches, the heat becomes so intense, that it will scorch and burn up the objects placed in or near the focus, and even fuse the magnifiers themselves.

Having determined on the diameter of your condenser, the next point to be considered is its focal length, which should be such that the prismatic dispersion may interfere as little as possible. If the focal length be too short, the image will be coloured, notwithstanding you have an achromatic object-glass; and if it be too long, it will occasion great strain upon the instrument. Those I have found to answer the best have been in about the proportion of four or five times the diameter. The foci and diameters of the field lenses (see E, Fig. VII.) must be decided upon by trial, after the magnifiers or object-glasses have been selected.*

Under any circumstances it will be evident, that whenever a single condensing lens is used, some portion of the light will of necessity be dispersed; but if there were substituted in its stead a portion of a paraboloid reflector, as proposed by the Rev. Mr. Packman, this defect would be entirely obviated, and you would therewith collect an intense spot of pure white light.

* See p. 87.

Fig. VIII.

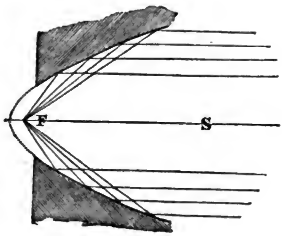


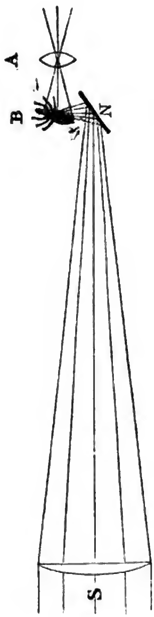
Fig. VIII. represents a section of such a reflector, with its apex cut off; F is its focus for parallel rays, within which the object is to be placed. By a principle of the parabola, all the rays of the sun impinging upon its surface will be reflected towards F, without aberration or dispersion; and thus the object intercepting them will be intensely illuminated without any coloured fringes.

Opaque Objects.

The usual method of constructing a microscope for displaying this boundless class of objects, in all their varieties and beauties, augmented by the reflection of the solar light condensed upon them, is shewn at Fig. IX., where S represents the condenser, B the object, N a small reflector, and A the magnifier. Since, in this case, the light is to be reflected from the object, and not transmitted through it, a plane reflector is placed at N, in order that the condensed rays falling upon it may be thrown upon the object, and thence proceed, as in the case of transparent objects, to depict its image on the screen. The reflector so used is generally a piece of looking-glass, acted upon by an adjusting screw from behind, so as to vary its inclina-

tion, and suit the different objects to be viewed; but here a small speculum would be an improvement worth the additional cost.*

Fig. IX.

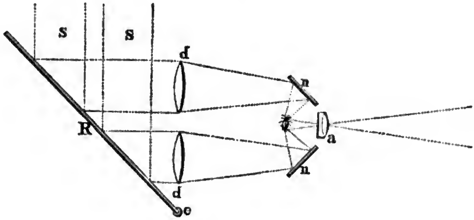


Another method of illuminating opaque objects is by means of four smaller condensers arranged in a circle, from which the condensed light, ere it arrive at their focal points, is received upon four small reflectors so situated as to throw the whole of the light upon the object. This plan will be readily understood by a reference to Fig. X., where *d d* represent two of the four

* See Fig. III. p. 85.

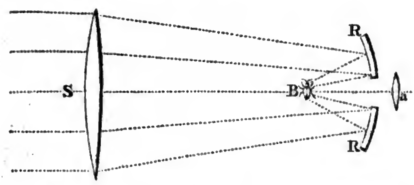
condensers, *n n* their corresponding mirrors, and A the position of the magnifier. An instrument thus constructed has been made in America, and found to answer very well.

Fig. X.



The following plan, contrived by myself, has many advantages. It consists of one condenser (the same as is used for transparent objects) and a silvered concave spherical reflector, or cup, with an aperture through its centre to admit of the condensed light proceeding to the magnifier. This arrangement is given at Fig. XI., where S is the condenser, B the object, R the concave reflector, by means of which the rays, partly condensed by passing through the lens S, are collected and thrown upon B, and thence proceed through the aperture to the magnifier or object-glass *a*.

Fig. XI.



By observing the preceding construction, it will be evident, that if the concave reflector R were of equal diameter with the

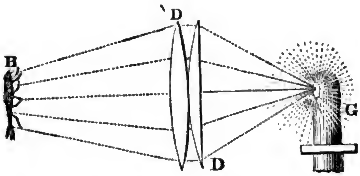
condenser D, the latter might be wholly dispensed with: this, doubtless, would be the simplest method of illuminating opaque objects, and at the same time would possess the additional advantage of exemption from refrangibility. But since, in practice, it is not advisable to construct a solar microscope that will not exhibit transparent as well as opaque objects, and since the condensing lens conduces effectually towards illuminating them both, it would be a wasteful expense to make the reflector of such large dimensions.

ILLUMINATION FOR GAS MICROSCOPES.

It has been assumed (which, however, is notstrictly true, although sufficiently so for practical uses), that the rays of light emitted from the sun are parallel to each other, and that it belongs therefore to the illuminating portion of the solar microscope merely to divert them from their parallel course, and make them converge toward the object intended to be illuminated. In the case now under consideration, the rays emanating from an artificial light placed at a short distance from the condenser are divergent, and all except the central ones fall obliquely upon the surface of the lens; hence a double operation must be performed upon them before they can be made, as in the former instance, to converge upon the object interposed for illumination: that is to say, it is necessary first to bring them parallel, and then, as in the instance of the solar, to converge them toward the object they are intended to illuminate. This, however, may be effected, as we shall presently see, with a single reflector also. In both cases the main object to be attained is to collect the greatest possible number of rays that can be taken up; to accomplish which with a lens, the surface next the light should be concave, or at least a plano, otherwise the rays nearest its margin will, owing to their great obliquity, be reflected from and not refracted

through it. From the numerous experiments I have made in constructing gas microscopes, I find the best arrangement for the illuminating part, when lenses are employed, to be similar to that shewn in figure 12; where a plano-convex lens, D, is

Fig. 12.



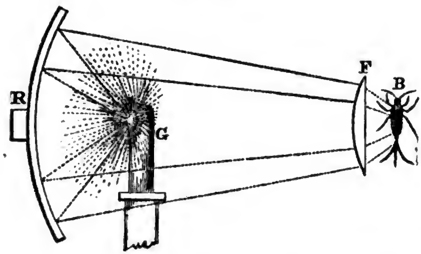
first placed with its flat surface next the light, G, and at such a distance from it as to bring the divergent rays nearly parallel; and then, in close connexion with it, a double convex lens, 'D, to condense them upon the object, B. In some instances I have used three plano-convex lenses, but I do not think the advantage obtained by thus dividing the refractions at the surfaces compensates for the loss sustained by the introduction of an extra lens*. The contrivance given at figure 12 answers so completely that it leaves little room for any improvement to be effected by a combination of lenses, an angle of light of between 50 and 60 degrees being taken up.

In order to increase the quantity of light, it has been proposed to place a reflector behind it, but this cannot be made to produce the desired effect unless its centre of curvature coincides with the radiant; for the reflected rays not having the same divergence as those proceeding direct to the lens from the light itself, cannot be taken up so as to afford any additional advantage in the illumination. If, however, a simple

* In cases where the diameters of the condensing lenses are great, and the focus short, it might be an improvement to use fluid lenses; or even, in some cases, Sir D. Brewster's polygonal lenses might be serviceable.

concave reflector properly constructed be used without any lenses, the result will be quite equal, if not superior, to that obtained by the preceding management, and at the same time will obviate one of the greatest defects there is to contend with, viz. that arising from refrangibility. This construction is given at figure 13, where R is the reflector, G the ignited lime, and

Fig. 13.



B the object: a field lens, F, is introduced in the diagram, and might be useful in some cases.

In gas microscopes constructed as above, with only a reflector for illumination, on removing the magnifiers in front the illuminated portion of the screen will not be a complete circle, the lime, jets, &c. interposing between the two, shewing their shadow upon it. I am informed by a person who has experimented with a reflector in this way, that we cannot obtain so great a range of distance between the screen and instrument as when lenses are used, so that a certain radius of curvature is suited to one distance only: of this circumstance I am unacquainted, not having observed it when making my experiments about four years ago.

Before proceeding to the consideration of the illumination of opaque objects, it will be advisable to introduce a few remarks on the above.

It has been stated in the Microscopic Cabinet, that objects

are best defined when viewed by diverging rays. In the solar microscope this is difficult to accomplish, but it will be seen that in the gas microscopes we have divergent rays; and I have little doubt but for large objects it would be a vast improvement to introduce them close to the condensing lens, on the side next the light. This arrangement would have the advantage of enabling us to reduce their diameter—a point of no small importance, as the thickness of glass in large deep lenses is considerable, and the loss of light appreciable.

In the solar microscope, the Rev. J. B. Reade has recently introduced astronomical slides, and those of the phantasmagoria, between the large reflector and condensing lens, with effect; and indeed all the best instruments of that kind should be provided with the means of such adaptation.

I cannot omit to notice a remarkable error which is to be found in all the optical treatises from Gravesande's down to those of the present day, respecting the construction of the phantasmagoria and magic-lanthorn. In all of these, the slide containing the figures to be projected on the screen is described and drawn as placed between the plano-convex bull's-eye condenser and the magnifier—that is to say, in converging rays, whereas, in practice, the slide is placed next the light, and close behind the bull's-eye, so that in fact they are in diverging rays, and the bull's-eye condenser and magnifier act as a doublet, and the distortion arising from the sphericity of the condenser is thus greatly diminished.

In my lucernal microscope, where a moderately magnified picture of the object is thrown upon a plate of greyed glass, for drawing its outline, &c., or for enabling several persons to view it at the same time, the principle of the optical construction which I adopt is similar.

Opaque Objects.

The simplest method of illuminating opaque objects in gas microscopes is by means of a concave reflector only, as shewn

in fig. 13; in which case, however, the object and the light, B and G, are required to change places, and the reflector must be provided with a sufficient aperture in its centre to admit of the rays of light proceeding freely from the object toward the magnifier behind it. By inspecting this figure with the alteration proposed, it will be manifest that the cone of rays incident upon the mirror will of necessity be very small, and consequently that large objects only can be sufficiently illuminated by it.

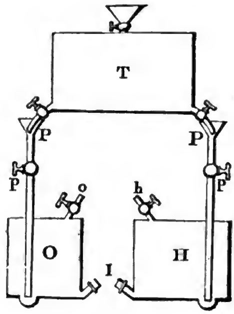
Another mode is to receive the rays at B, (fig. 12) upon a concave reflector, similar to that represented in fig. 11; but it may be remarked, that in no instance has it been practicable to introduce, for displaying opaque objects, magnifiers of equal powers with those used for transparent ones, and solely on account of a deficiency in the illumination.

Though the description of an apparatus answerable for the purposes of containing the gases and regulating a due supply of them for combustion, should in strictness fall within the province of the chemist rather than the optician, still, as the subject seems to be almost naturally brought under our consideration, a few observations respecting it will contribute, I think, towards rendering this tract so much the more complete. Before I proceed, therefore, with the rules necessary to be observed in the management of the instruments themselves, I shall take this opportunity of stating some particulars as to the regulation of the gases. It is scarcely requisite to mention the propriety of having every part of a gas apparatus, together with all the pipes, stop-cocks, joints, &c. used in connexion with it, perfectly air-tight, both as far as safety is concerned, and to prevent the waste and loss of a valuable commodity.

Fig. 14 exhibits the form of an apparatus suitable for the purpose. O and H are two cylindrical vessels of sufficient capacity to contain gases for one or more representations; P P are two pipes, with stop-cocks at *p p*, and apertures to admit of their discharging themselves into the bottom of the

vessels O and H; T represents a tank or reservoir of water, to

FIG. 14.



supply an uniform pressure or force to expel the gases from the vessels; *o* and *h* are exit pipes fitted to communicate with the jet, where the ignition is to take place. The action of this apparatus is as follows: the vessels, O and H, being filled with the gases, and the closed tank, T, with water, the pipes *o* and *h* are to be attached by means of union-joints to the feeding pipes of the jet. If the stop-cocks of the tank are now opened, the funnels at P P will be filled with water, on the principle of the common bird fountain; the lower cocks, at *p p*, may then be opened, when the water issuing from the apertures at the bottom of the pipes will ascend in the vessels, and so compress the gas that it will exert itself to escape. The pressure of the water against the under surface of the gas will be equal to that of a column of water of the height of the water in the funnel above that to which it can ascend in the vessel; the pipes, P P, must therefore be of sufficient length, viz. 20 to 30 inches, to admit of the pressure overcoming the resistance occasioned by the gas passing through the tubes, and to discharge it from the mouth of the jet with sufficient

force against a body of lime prepared for combustion.* The stop-cock at *h* may now be opened, and the hydrogen gas issuing from a proper aperture in the jet must then be inflamed. In like manner, the stop-cock at *o* being turned, a due supply of the oxygen will also be furnished.

The mode of filling the vessels with the gases may be thus explained: the stop-cocks at *o h* and P P being opened, the water from the tank will flow freely into the vessels O and H; as soon, then, as they are filled, let all the stop-cocks be closed. The caps of the induction orifices or shallow tubes situated at I, should next be unscrewed, and the extremity of the small pipe through which the gas is to pass inserted at the induction orifice: as the gas rises to the top of the vessel, and there displaces the water, the latter will continue to flow out at I, until the vessel is filled with gas, when, the caps being screwed on tightly, the apparatus will be ready for use.

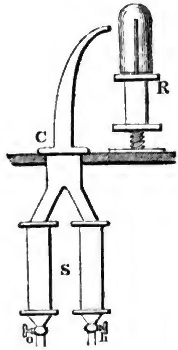
I would here remark, that each of the vessels should be furnished with a glass gauge-pipe, communicating with the interior, for the purpose of indicating the quantity of gas in the vessel, and how much is consumed in a given time. It may also be stated, that if there be no gas in the vessels or feeding tubes, the water will be liable to be expelled from the jet, destroying the lime, and otherwise damaging the apparatus. The tank should be constantly filled with water, which may readily be done, whilst the lower cocks are closed by means of the funnel at the top. The great advantage, however, of my closed tank over an open cistern is, that the pressure upon the gases is regulated by the length of the pipes, P P, without any reference to the variable height of the water in the tank. This is a point of vast importance, inasmuch as the intensity and steadiness of the light will depend entirely upon an uniform

* It will be found in practice much better to employ only one funnel and stop-cock to the tank, T, and make the pipe, P, branch off to each vessel: I have recently learnt that Mr. Maugham has proposed the latter plan, but in place of the tank, T, he uses a ball-cock to regulate the supply of water.

pressure: with a varying pressure the brilliancy of the image on the screen will be continually varying also.

Fig. 15 illustrates a method of constructing the jet, and how

FIG. 15.



the lime is disposed for combustion: *o* and *h* represent the feeding-pipes of the jet, which are to be attached to the corresponding tubes of the vessels O and H, designated by the same letters. At S are situated two of Hemming's safety-tubes, containing bundles of fine copper wire, gauze, or asbestos, to cool the gases, and prevent explosion, should any accident occasion the ignited gas to return towards the vessels. When speaking of the *return* of the gases in the direction of the vessels, and thus forming in the tubes, or vessels themselves, an highly explosive mixture, there is one point to which I have not yet alluded, but which I conceive to be of the greatest possible importance; and it is this—viz. that the areas of the bases of the vessels H and O should bear exactly the same proportion to one another as that in which the hydrogen and oxygen gases, in reference to volume, are required to be used for consumption. The necessity of this will be sufficiently manifest, since more than twice the quantity of hydrogen to that of oxygen is expended in producing

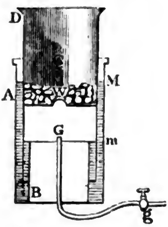
the requisite light. Whilst the gases are being consumed, their under surfaces, in the vessels H and O, by the proposed arrangement will be continually kept at equal altitudes; and since the water ascends to these under surfaces, and the pressure there exerted is dependent upon these altitudes, as before mentioned, the pressure in both vessels will remain uniformly the same. By admitting, therefore, twice as much hydrogen as oxygen to pass through the stop-cocks of the feeding-pipes of the jet, the two gases, in their due proportion, will arrive at the mixing-chamber, C, pressed forward by equal forces; nor will there be any disposition in the one to overcome the force of the other, and thus to repel the mixed gas from the chamber, C, back into either of the vessels, but it will proceed steadily on to the mouth of the jet, and so much of the gases only will be admitted to mix as can be contained in the *small* chamber at C. R represents the rod upon which the lime, in the form either of a sphere or cylinder, is sustained—(the latter form for ordinary uses is generally preferred.) In either shape the lime, by means of clock-work, or the hand, should be made to revolve, and thus present a new surface to the ignited gas, otherwise it will be liable to burn away unequally, and to burst. The lime cylinder is sometimes placed horizontally, and the flame brought to play upon its base; but this arrangement does not afford so steady a light, and a cavity being soon produced by the combustion, a strong shadow will be thrown upon the screen.

I next proceed to describe an apparatus of a different construction, and possessing the immense advantage over the other of requiring but a comparatively small quantity of water for its use. I conceived the plan of this from reading an account of one constructed in Turkey, on a similar principle, by Mr. W. H. Barlow.* Mine differs from that gentleman's, however, in two material respects: 1st, I am enabled to dispense with a vast proportion of the water requisite for his apparatus; and, 2dly, by substituting weights in the place of water, I give it

* See Phil. Mag. vol. viii. p. 240, 3d Series.

additional steadiness, by bringing down the centre of flotation to a much less elevated point. Let A, fig. 16, be a section of

FIG. 16.



a cylindrical vessel composed of copper or tin, and connected at the bottom to a small cylinder in the situation of B. A third cylinder, D, of equal length with A, and about three inches less in diameter, is so placed within the vessel A that it can be moved up and down with perfect freedom, and admit of a small quantity of water being contained between its outer surface and the inner surface of A. The cylinder D is furnished with a diaphragm, situated at such a distance from its lower extremity that when D shall descend to the bottom of the vessel A, the diaphragm may coincide with the upper extremity of the cylinder B. The cavity represented at B will be of nearly the same dimensions as are required in the vessel D, to contain a volume of gas sufficient for a specified time. The operation of this apparatus is as follows: a small quantity of water is poured into the vessel A, and D is then inserted into it. The stop-cock at *g* being opened, as the diaphragm and cylinder D descend to B, the atmospheric air issuing through the orifice at G will pass along the pipe, and make its escape at *g*. If the gas be now admitted at *g*, it will occasion the floating vessel, D, to ascend in A, until the space G is taken up by the quantity of gas required. The stop-cock, *g*, may then be closed, and the water in the vessels will stand at the same level, *m*, within and without the floating

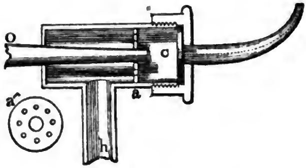
vessel, D. If weights are now placed at W, in the cylinder D, and additional water be poured into the vessel A, it will rise on the outside above *m* to some height, M, to be determined by the requisite amount of pressure. On opening the stop-cock, an uniform supply of gas will then be discharged at *g*, and as the cylinder D descends, the water will remain constant at the levels M and *m*. When it is necessary to replenish the vessel with gas, the weights at W must be removed by the hand, or otherwise, and the operation conducted in the order previously described. In Mr. Barlow's apparatus, the spaces represented at B and W, the part of D situated above its diaphragm, are occupied with water, which, in case of leakage, may be exceedingly troublesome, and must be always inconvenient, from the necessity of removing the whole of that contained in D, whenever the vessel is to be refilled with gas. Further, in order to obtain the requisite pressure with water, the portion of D over the diaphragm must be nearly filled with it, when its centre of gravity will be somewhere at C; but in the case of weights, when sand, stone, or metal of greater specific gravity than water, is used, the centre of gravity will be somewhere at W, which being below M will render the flotation far more steady than if it were above it, at C.

Since the gases must be kept apart from each other, the like construction will be required for the use of each; and the cylindrical vessels of the two apparatus being made of the same elevation, should be so proportioned with respect to their diameters, that the same height of gas may be consumed from the one as from the other in a given time.

The description of jet used by Mr. Barlow is shewn at fig. 17: it is commonly known as Daniell's jet. It consists of two tubes, *a* and O, the one inserted within the other, in the manner represented by the figure. The outer tube (*a*) has a diaphragm situated at *a*, through which a portion of the inner tube (*o*) is admitted into a mixing chamber at *c*. This diaphragm is perforated with small holes, to allow the hydrogen gas to pass from the feeding-pipe (*h*) through the holes *a* into the chamber,

c; and that portion of the tube O situated within the chamber,

FIG. 17.



c, is perforated also, to admit the oxygen from the tube O to mix with the hydrogen in the chamber, c, and, in that condition, to proceed to the mouth of the jet. I prefer this arrangement to the one given at fig. 15, because it is not so liable to be injured, should any water, as will sometimes unavoidably happen, be forced through the pipes into the jet. As the gases burn much better when dry, it might be desirable to pass them through a vessel containing anhydrous muriate of lime, to free them from moisture.

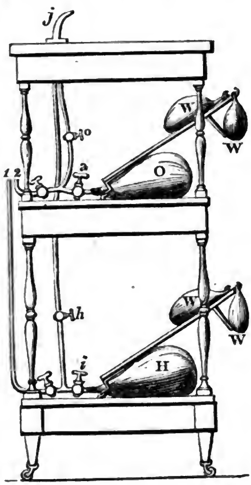
I shall now describe a portable apparatus, in which the gases are contained in bladders, or bags made of cloth or leather, rendered air-tight by a coating of caoutchouc; and the pressure is managed entirely without water, by the application of sand-bags or weights*.

Figure 18 represents a side view of the apparatus. It consists of a square frame of wood, running on castors, and furnished with horizontal partitions or shelves upon which the bags or bladders, O and H, containing the gases, are to be placed; the upper shelf being usually preferred for the oxygen gas, in order that the stop-cock at *o* may be the more readily adjusted, and the lower shelf for the hydrogen. Small pipes, with stop-cocks, as shewn at *o, a, i,* and *h,* are annexed to the different bladders, and made to communicate with the jet, J. On the upper shelf stands a purifier, hereafter to be described,

* Hydrogen being transmissible through most bodies, the bags or bladders should not be filled until wanted for use.

for freeing the gases of their impurities, so that, without passing through any other intermediate vessels, they may, as soon as generated, be conveyed at once into the bladders, O or H, to

FIG. 18.

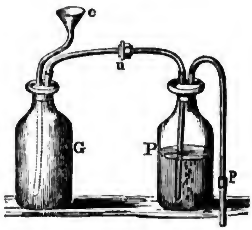


be used when requrired. W W are the weights, or sand-bags, pressing, by means of inclined boards, upon the distended bladders, and thus, in conjunction with the stop-cocks, acting as regulators for the steady and proportionate supply of the gases. It is scarcely worth mentioning that, during the time the bladders are being filled, the weights and boards must be of course removed*.

* The method by which the pressure on the gases is obtained in the apparatus figure 18, has been objected to, as it varies with the inclination of the boards to which the weights are attached: to remedy this inconvenience, the gas-holders might be constructed similar to the *receivers* of organ-bellows. See Edinburgh Encyclopædia, vol. xv. p. 676, plate 447, figs. 5 and 7.

The addition of a few words more on the practical method of generating and purifying the requisite gases, will, I think, be in strict conformity with the design of the present tract, and suffice to render this part of the subject tolerably intelligible to the generality of readers, It has been already noticed, that a bottle, termed a purifier, is placed, for convenience sake only, on the stand at P ; and, on the other side of it, not discernible at a side view, is stowed a leaden bottle also, adapted for the purpose of generating the hydrogen gas. Fig. 19 represents

Fig. 19.



these two bottles, taken from their respective situations, and now supposed to be employed in the order they are exhibited. Some water and granulated zinc are first put into the leaden generator, G, (about a pint of water and a pound of zinc will be sufficient,) and the purifier, P, is about two-thirds filled with water. The bottles are then securely corked, and a communication is established between them by tubes perforating the corks, and brought into connexion with each other by an union-joint at *u*. In like manner the tube at *p* is made to communicate successively with the pipe, 1 or 2, of the several bladders intended for use. If a small quantity of sulphuric acid (about half a wine-glassful) be now poured into the funnel at *c*, a portion of the water will be decomposed, and the hydrogen gas speedily evolved, and pass through the purifier into the bladder or bags, H: when the evolution becomes languid, fresh acid

may from time to time be added, until the needful supply of gas is obtained*.

The mode of generating and purifying the oxygen gas is extremely simple, and may be very summarily explained. If an iron retort partly filled with lump manganese be inserted into a strong fire, as soon as the manganese attains to a red heat it will part freely with the oxygen it contains; and if a communication be made between the retort and the purifier, P, by means of a long tube, the oxygen will pass over into the purifier, through 2 and *a*, into the bladders at O, in the manner before described for the hydrogen. Thus the same purifier will serve for both gases: too much care, however, cannot be taken to retain the gases quite separate from each other, and not to risk the possibility of an explosion. I would caution also against the purifier being more than two-thirds filled with water, lest any of the water should be conveyed to the bladders and destroy them. The quantity of oxygen that can be contained in the bladders suited for the apparatus I have now described will sustain a light for one hour; that of the hydrogen for about half that time; but since the latter can be very readily procured, little, if any, delay will be thereby occasioned.

ON THE MANAGEMENT OF SOLAR AND GAS MICROSCOPES.

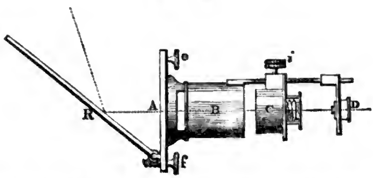
In selecting a room for a solar microscope, the first consideration should be, that the aspect be towards the south, so that from the window, in fine weather, you may command a view of the sun for the greater portion of the day. This room must be provided with the appropriate white screen, constructed on the wall immediately opposite the window; ex-

* The apparatus, figure 18, would be found useful for many chemical experiments, and especially for exhibiting the combustion of metals by the mixed gases.

cepting which, every other part, ceiling, walls, &c. should be rendered, as before mentioned, as dark and sombre as possible. On this arrangement, and the brilliancy of the day, will very much depend the beauty of the representation. The size of the room should be in a great measure regulated by the nature of the exhibition: where many persons are to assemble, it should be well ventilated and large; and in no case should the distance from the window to the screen be less than ten or fourteen feet, as this will have much to do in determining the extent of the illuminated disc upon which the image is to be thrown, and the magnitude of the image itself. The diameter of the disc should be about one half the distance between the window and the screen. The window must be closely fitted with a firm shutter or board, in the centre of which must be cut an aperture suitable for the reception of the instrument: thus all the light will be excluded but that which is to pass through the instrument and illuminate the screen. If, however, the shutter be furnished with an additional opening, which may be readily closed when necessary, it will be found extremely convenient for the purposes of ascertaining the position of the clouds, the state of the weather, &c.

Figure 20 represents the external appearance of a solar

FIG. 20.



microscope:—A, a side view of a square metal plate, which is to be firmly fixed to a window shutter; B, the tube containing the condensing lens: between this lens and the plate, A, is an aperture for the admission of large phantasmagoria and other slides; near the end of the tube is attached a bar, with a rack

for carrying the slider-holder and magnifiers; C, the said slider-holder, with its field-lens; and D the arm for holding the magnifiers; R is a plane mirror, which is exposed to the sun, and capable of being adjusted to its azimuth and altitude by means of the milled heads, *e* and *f*.

This adjustment requires adroitness, in order to keep pace with the varying position of the sun: the great object of it is that the sun's rays may be reflected from the mirror directly along the axis of the instrument, so as to form, after passing through the condensing lens, a circular disc upon the screen: when this is obtained, it will be a certain test that the adjustment of the reflector is correct. Some little care is requisite, in showery weather, that the reflector be not injured from becoming wet. At a convenient distance should be stationed a suitable table, or shelves, for containing the various parts of the apparatus, vessels containing objects, &c. which should be disposed in such order that they may come to hand readily in the dark. If, however, it can be easily obtained, a small inclosure, just sufficient for one person to manage the instrument, will be found of great advantage. This may be fitted up with every convenience, and a little light being admitted into it will not affect the appearance in the room itself. If the magnifier be now inserted into the tube D, and the arm moved backwards or forwards until the disc be entirely illuminated, the object may then be placed within the slider-holder, C, and adjusted to the magnifier at D, and thus a distinct image, or picture of it, will be thrown on the screen.*

The sliders for inclosing the various living objects must be kept clean and dry; and all the objects, whether animate or inanimate, should be carefully arranged in the order they are to be viewed. A few small white basins or saucers, with some

* I am informed by the Rev. J. B. Reade, that it is preferable to place the field-lens beyond the focus of the condenser, by which means the intense heat produced at that point is avoided, and the objects or magnifiers preserved from injury. Mr. Reade has had so much practice with the solar microscope that his opinion is valuable.

feathers, &c. for transferring the living objects into the sliders, will be useful. For a few minutes previous to the exhibition, the room should be retained in total darkness; or if a little light be necessary, it should be supplied from a *common* lamp; the reasons for which are these: in darkness the pupil of the eye dilates, and becomes capable of discerning the minutiæ of objects with greater facility and exactness; and the dull yellow flame from a common lamp, by its contrast with the resplendent whiteness of the sun's light, serves but to heighten the effect.

The selection of objects should greatly depend upon the taste of the company to whom they are to be shown. When amusement and general instruction are principally aimed at, large living objects, such as aquatic larvæ,* &c. will answer the purpose very well; also the splendid wings of foreign butterflies; thin sections of fossil woods, charcoal, jet; the circulation in animals and plants; solutions of salts made to crystallize by evaporation: and silver from a state of solution precipitated upon small pieces of copper wire, thus forming what is called the silver tree;—all these will prove highly interesting when viewed under the miscroscope. And if to these be added the various manufactured fabrics, such as lace, blond, muslin, and the like, and the contrast displayed between them and the transverse sections of different woods, plants, &c., I know of no exhibitions that will serve better to elucidate the perfection and pre-eminence of Nature's structures over the most ingenious contrivances of art, and to engraft upon the youthful mind impressions, not soon to be obliterated, of the Almighty hand that created them.

To the more scientific observer, objects in detail will be of deep interest: for instance, the proboscis of the fly, its feet, &c.; the lancets of some insects; the tongue of the bee; the singular and delicate forms of the different infusoria, and the arrangement of their internal organization; the markings on

* See Microscopic Illustrations.

the scales of butterflies, moths, &c.; sections of fossil woods, and longitudinal sections of woods of recent growth: in short, myriads of specimens may be procured, both of vegetable and animal structures, accommodated to the intellect of every human being, and calculated to advance the most profound philosopher a step onward in the great path he is journeying, toward comprehending, as far as the mind of man can comprehend, the immensity, beauty, design, and order of God's works.

As much, however, will necessarily depend upon the selection of magnifiers suitable for particular objects, it is advisable to arrange the objects according to their size, commencing with the greater ones, which require only shallow magnifiers, and gradually proceeding to those which are to be viewed with the deepest powers. Notwithstanding, it will leave a good impression, ordinarily, to conclude with representing a collection of large living objects under the lowest power of the instrument. Whilst changing the object or slider, a screen should be placed before the instrument for the purpose of excluding the extra light which would be otherwise admitted, and tend in a great degree to destroy the effect, by causing the pupil of the eye to contract.

Although the preceding remarks may seem to refer especially to the solar microscope, still, as both that instrument and the oxy-hydrogen gas microscope resemble each other so very closely in most particulars relating to management, it would be almost a repetition of words to give them, in this respect, a distinct consideration. If, then, we substitute the regulation of the gases, the adjustment of light as to distance from the condenser, and the arrangement of the lime-ball, or cylinder, for the employment of the sun's light by means of the plane reflector, little more will remain to be said upon the subject. As very much of the effect will always depend upon the qualities of the lime, I would recommend the trial to be made of all the various descriptions of lime that can be easily procured; and after they have been well baked, let that be selected which,

without bursting, affords the steadiest and most brilliant light. In putting the gas apparatus into action, the hydrogen should be turned on first, and the light instantly applied to it; after which, by a due supply of oxygen, the dull bluish-red flame will gradually change its character until the lime situated near the mouth of the jet shall become entirely ignited, when it will be succeeded by an exceedingly intense white light. If too much oxygen be admitted, the light will be totally extinguished. A very little experience, however, with some attention, will enable any one to form a true judgment as to the correct proportions.

I shall conclude this little treatise by appending a few cursory observations.—The solar microscope is admirably adapted for tracing with a pencil a magnified likeness of any minute object, which may be done with great facility and precision by placing a sheet of white paper in front of the screen, and throwing the image directly upon it. The exact proportions of the different parts, and their relative situations, by far the most difficult points to be attained in drawings of this nature, (see Microscopic Illustrations, on this subject,) may thus be achieved by merely the mechanical motion of the hand. When living objects are to be drawn, what are termed angular sliders should be provided, to retain them; for, when placed in these, they will soon, by their restlessness, thrust themselves into situations of restraint well suited for the purpose. This form of slider will also be found extremely convenient for showing the circulation in the water-newt, or any small fish. If the drawing of objects be principally aimed at in the use of the instrument, a small moveable screen, expressly constructed for it, of just sufficient dimensions to take in the projected image, may be interposed between the instrument and the original screen; also, its texture being appropriate, the image will be seen more distinctly behind the small screen than in the front of it, in which position there will arise no obstruction to the drawing, from the shadow of the hand.

EXPERIMENTS ON THE POLARIZATION OF LIGHT WITH THE SOLAR OR GAS MICROSCOPES.

In most of the different arrangements for viewing the wonderful and oftentimes beautiful phenomena displayed by various bodies, when submitted to the action of polarized light, the quantity of light which can be obtained is so extremely small, that very faint impressions consequently result from it. In solar and gas microscopes, where an abundance of light is readily supplied, all these properties may be exhibited with exceeding brilliancy; for which purpose a slider must be so contrived, that the crystal, or other bodies to be examined, may be placed between two plates of tourmalines, or two single image calc prisms, bundles of glass plates, &c.

When a transparent object is placed in the solar or gas microscope, the illuminated disc, upon which the image is viewed, is made up not only of the light which is transmitted through the object itself, but of that portion also which, not having come into contact with it, passes more freely through the instrument. This extraneous light, in cases where a delicate object is exhibited, has so great a tendency to subdue the image, that but a very faint impression of it is produced upon the screen. Opaque objects, the representations of which are seen entirely by the light reflected from them without the interruption of any extraneous light, have all their beautiful markings and colours displayed in the greatest possible perfection. From the intense heat, however, always accompanying the condensation of solar rays, very minute objects are liable to be too seriously injured (if not absolutely burnt up) to be risked in solar or gas microscopes: those of moderate size, therefore, are necessarily used, many of which, such as small flowers, shells, &c., and the *basso relievo* on medals, will be found to be highly interesting.

In exhibiting the internal structure, circulation, pulsation, and peristaltic motion of the alimentary canal and other organs of aquatic larvæ, &c., * specimens should be selected immediately subsequent to the shedding of their skins, in which condition the exterior covering is much thinner and more transparent than at any other period of their existence. If the same living objects are to be preserved for a second use, care must be taken that they be provided, on being removed from the instrument, with fresh water of a temperature not much below that of the water which is contained in the slider; for, by suddenly immersing them in cold water after they have been heated by the sun, you would inevitably destroy them.

If the carnivorous aquatic larvæ of insects be kept hungry in clear water for a short time previous to their being viewed, and then provided with appropriate food, or, in its absence, with the eels found in sour paste, for which they have a relish, their peculiar mode of satisfying their voracious appetites will be a subject of curious examination. The eels in paste, and many of the infusoria, are often so exceedingly crowded in the vessels that contain them, that additional clear water is absolutely necessary before you can obtain a distinct representation of them. This operation will be performed with good effect whilst they are under the instrument; or, what perhaps may be more convenient, let a slider furnished with a due quantity of clear water be first placed within its holder, and then add a drop of the infusion including the animalcules.

Among aquatic larvæ, the most beautiful and delicate are those of the numerous species of gnat, but more especially that of the straw-coloured one (*Chironomus plumosus*) described and drawn in the Microscopic Illustrations; the larva of some May flies, such as that of the *Ephemera marginata,* given in the same work. For these creatures a deep vessel or slider should

* The "Microscopic Cabinet" and "Illustrations" contain descriptions and drawings of avariety of the most choice living objects for these instruments.

be obtained, and the instrument should admit of it moving upwards and downwards, as they rise occasionally for respiration.

I have just hinted at the disadvantageous consequences, in reference to the use of these instruments, resulting from the association of heat and light; in short, that numerous objects would be totally destroyed, if subjected to that intensity of heat which universally accompanies the acquisition of a sufficiency of light for illuminating solar and gas microscopes.* The inference to be drawn from this consideration is, that these two instruments are necessarily much restricted in their use, because, requiring, as they certainly do, a far more powerful light than other microscopes in order to give an equal effect, a multiplicity of objects in every way adapted to other instruments are thereby wholly excluded from them. To do away with this obstruction to extending the power of these microscopes to their utmost capability, I have interposed transparent media between the condensed light and the objects, such as a large slide, filled with clear water, placed immediately behind another containing delicate living objects, and thereby in a great degree reduced the heat. It appears, however, from the valuable experiments recently made by M. Melloni "*On the free transmission of radiant heat through different solid and liquid bodies*,"† that heat and light may be separated to a very great extent; for some bodies, while they transmit nearly all the heat, do not transmit any light; and for our purposes there are several diaphanous substances which transmit very little heat, as alum, the salts of soda or potash, fluor spar, &c. Thus, out of 100 incident rays, the following pass through the same thicknesses of—

Ice very pure	(diaphanous,	colourless)	6
Sugar melted,	(do.	yellowish)	7

* In the gas microscopes, a plate of mica placed between the light and the first condenser will prevent the latter from breakage by the heat.

† Annales de Chimie et de Physique, t. 53, p. 1, and t. 55, p. 337. Also see an excellent translation in the first part of the Scientific Memoirs.

Alum,	. . . . .		9
Citric Acid,	. .	(colourless)	11
Gum, .	(diaphanous,	yellowish)	18
White topaz,	(do.	colourless)	33
Glass,	(do.	do.)	39
Fluate of lime,	(do.	greenish)	46
Rock salt	(do.	colourless)	92

A. P.

CHAPTER IX.

I.—*On Cuvier's Method of Dissecting Microscopic Subjects under Fluid; with Additions.*

II.—*On a new Method of obtaining a delicate Adjustment to the Focus of Microscopes.*

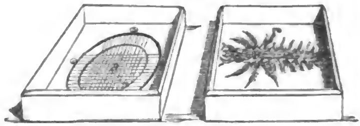
III.—*On an improved Mode of Supporting a Candle or Lamp for Microscopes.*

1.—CUVIER'S METHOD OF DISSECTING MICROSCOPIC SUBJECTS IN FLUIDS, WITH ADDITIONS.

Being requested some years ago to make a dissecting apparatus to a microscope, similar to that usually employed by Cuvier, which consists of a metallic trough, similar to fig. 22, it occurred to me that for many purposes, where the subject under dissection was not quite opaque, a glass bottom to the trough would be an improvement, and accordingly I made some, and have found them very useful, as sufficient transmitted light is often obtained. The addition also of coarse micrometer lines, cut on the disc of glass, renders it more complete. One of these troughs is shown at fig. 21: they are attached by a bayonet-joint to the common stage, or fit

into the moveable one at *o*, fig. 1, plate 1, and can thus be turned in any direction.

FIG. 21. FIG. 22.



M. le Baron Cuvier's method of using these troughs is as follows:—Take a composition of bees'-wax and Venice turpentine, or Canada balsam, and line the trough with it while warm; then lay in the subject to be dissected, first having dried the parts that are intended to be fixed to the composition, and when the whole is cold, the dissection may be commenced, the trough being first filled with water*.

By fixing a subject in this manner its parts are more readily separated, and being covered with a fluid, the adventitious portions are easily washed away with a camel's hair pencil.

The knives used for dissecting microscopic subjects, are usually made similar to those employed by oculists for operations on the eye, and the scissors, described in the "Cabinet," page 243, are highly useful. When the subjects are minute, I have found a great advantage in having the small cutting instruments fitted into handles, in which their lengths and consequent elasticity can be varied, and for these handles,

* Microscopic dissections are of great value; they are now beginning to be appreciated, and ought to be encouraged. It is impossible to determine, with accuracy, the organization and functions of the smaller tribes of animals and vegetables (which, from their numbers, often produce serious consequences to man), without careful dissection of them. In my humble opinion, it is to be regretted that the Society of Arts, in place of rewarding Cuvier's troughs, which are not new, had not rewarded the candidate for his industry and patience in making microscopic dissections, and thus have directly promoted this valuable and important branch of natural history.

needles of various kinds, especially the leather-workers', when ground on a fine hone, afford very useful instruments for dissections.

II.—ON A NEW AND SIMPLE METHOD OF OBTAINING A DELICATE ADJUSTMENT OF THE FOCI OF MICROSCOPES.

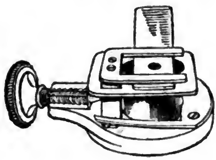
In Chapter XV. of the Microscopic Cabinet, I have described the various methods by which the adjustment of the focus of microscopes is effected; such as the rack-and-pinion, the screw, the bent lever, and the excentric*, with their various advantages and defects. I have also minutely described a plan of mine, by which a coarse and fine movement may be readily obtained. This is the primary object to be accomplished. Now although that method is unobjectionable for the microscope, where single lenses or doublets are used, yet it is not so when applied to an engiscope (that is, compound microscope), the size and weight of the body to be moved rendering it unsteady. To remedy this defect, various ingenious contrivances have been devised, retaining the rack-and-pinion movement, for coarse adjustment, and applying the finer one to the stage which carries the object. All these methods, however, where the desired effect has been obtained, have been so complex, that it is not likely they will come into general use. Under these circumstances I was led to construct the following, which it is not probable will be surpassed in simplicity or effectiveness, and, what is of great importance, cannot be easily deranged. Figure 23 is a perspective view of it.

It consists of a plate attached to the stage of the instrument: on this plate is fixed a socket for holding a fine steel screw with a conical point, which latter acting against a block

* See Treatise on Optical Instruments, p. 36, fig. 36.

carrying the object held in a safety slider-holder, is forced upwards by the conical end of the screw acting as an inclined plane, while a spring is so arranged as to keep it down to its bearing. The milled-head of the screw, if required, might be divided, by which means the elevation or depression would become a measured quantity.

Fig. 23.



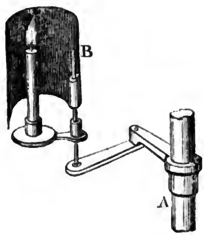
III.—ON AN IMPROVED MODE OF SUPPORTING A CANDLE OR LAMP FOR MICROSCOPES.

Observers with the microscope are fully aware of the importance of the proper illumination necessary to make that instrument produce the best effect: much depends upon the direction of the illuminating source, and when once properly arranged, any accidental alteration destroys the effect, and the whole must be commenced afresh. From these considerations I have been induced to attach the holder for carrying the candle or lamp to the stand of the instrument, as shown in the sketch below, by which the not unfrequent movement of the instrument, especially when more than one person is observing, will not affect the direction of the illumination, as all will move together. I am convinced those who have much employed a microscope will appreciate this trifling improvement, and approve of its introduction in this work.

A is the stem of the stand of a microscope; on this the socket slides to the required elevation, and the arms allow of the light being placed in any direction. B is a shade, to take off the direct light from the observer.

A. P.

FIG. 24.



APPENDIX.

No. 1.

ON MAKING DRAWINGS OF MICROSCOPIC SUBJECTS;

In a LETTER, *by* FRANCIS BAUER, *Esq. F.R.S. F.L.S.* *&c. &c.*

DEAR SIR,

I FEEL great pleasure in complying with your request, by explaining my method of making correct magnified drawings with microscopes. I often wished to have an opportunity to publish such an account; and I think your forthcoming "Micrographia" would certainly be the most proper for promulgating such a useful subject.

The requisite apparatus for ascertaining with a microscope the correct dimensions and proportions of any minute object, are two glass micrometers, each of forty divisions to an inch, and crossed or squared over their whole surface, similar to those you made for me. One of them ought to be pretty sharply engraven, on a very thin and clear plate of glass: this micrometer is fitted into the eye-piece in the focus of the eye-lens; the other micrometer, which is used on the stage, ought

to be very strongly engraven, and its lines well blackened, that they might be distinctly seen when viewed through the micrometer in the eye-piece. When my microscope was thus armed and adjusted, I ascertained the acting magnifying powers of its objective lenses, which is effected by placing the stronger engraved micrometer on the stage, and viewing and carefully observing, through the micrometer in the eye-piece, how many divisions are occupied by one division, or fortieth part of an inch of the micrometer on the stage: I found that with the objective, No. 2, it occupied precisely ten divisions each way, and consequently divides one linear inch into 400 parts, and one square inch into 160,000 squares.

Having thus ascertained that every division of the micrometer in the eye-piece is equal to a 400th part of an inch on the stage, and every square on that micrometer represents a 1-160,000th part of a square inch, I now retain this adjustment of the microscope permanently, and have no more occasion to use any micrometer on the stage for future operations.

When I wish to make a magnified drawing of a very minute object, I trace on my drawing-paper a number of squares, similar to those on the micrometer, of which each division is an inch (linear), which consequently is 400 times longer than a 400th lineal division on the micrometer in the eye-piece (see fig. 1, plate 3), I then place the minute object, which I wish to measure, on the stage, view it through the squared micrometer in the eye-piece, and move the object on the stage, till it comes into a proper position to be easily examined; that is, till one extremity of the object touches one line of the square on the micrometer in the eye-piece. I then trace on my ruled drawing-paper a correct outline of the object, as in fig. 1, A, B, C, D, E, and find that A is 2½-400th parts of an inch long, and about 1-900th part of an inch in breadth or thickness. B is 2-400th parts of an inch; C, 1-400th; D, 1-800th part: and the three very minute fossil animalcules at E, about 1-1200th of an inch in length, and proportional

in breadth. The globular fungi at F are 1-1600th part of an inch in diameter, and the very minute globules of blood at G are each about 1-2400th or 1-2500th part of an inch in diameter.

Having thus secured correct outlines of all the objects under examination, I finish the drawing by reviewing the objects with another microscope of higher power (perhaps 300 or 400 times,) by which I am enabled to introduce and mark correctly all the minute parts of the objects. All the objects represented at fig. 1 are magnified 400 times linear, and 160,000 times superficial.

I must here remark, that in all my microscopic drawings I have used the English measure.

I must also notice, that in adjusting the microscope for ascertaining its magnifying power, great care must be taken that the lines of the square of the micrometer on the stage exactly join and encompass the lines on the squares on the micrometer in the eye-piece, which is not always the case, or with some objectives the image may perhaps be found to occupy *nine divisions and a fraction,* which would occasion much calculation and trouble to produce a correct drawing*; but this difficulty is easily obviated, when the microscope is constructed with sliding tubes, for by elongating or shortening the tubes, the instrument can be adjusted to the greatest exactness, and on that adjustment depends the correctness of the whole.

When I intend illustrating objects which are larger than 1-40th part of an inch, and would be uselessly increased if magnified 400 times linear, I rule the drawing-paper into squares or divisions of half an inch, and proceed in every respect as in the former case: the drawing thus produced will be magnified 200 times linear, or 40,000 times superficial, (see fig. 2), and again, for drawing larger objects, I make the divisions of my paper of one-fourth of an inch, which

* See Chapter II.

will produce a figure magnified 100 times linear, or 10,000 times superficial, (see fig. 3, plate 3).

When I have wished to investigate and draw large opaque animal substances, such as the inner coats of the stomach, the papillary vessels of the tongue, or the internal structure of the lungs, or the spleen, &c. &c. (all such objects must be examined under water, and cannot be brought under the microscope, and no glass micrometer can be used)—I conceived and used another method, viz., I had several silver plates (of about a square inch, and about the thickness of a shilling), constructed, and in the middle of them regular and accurate square holes or perforations cut out, from half an inch to a 1-10th of an inch linear, (see fig. 4, plate 3.) When I wished to examine such opaque objects under water, I placed one of these plates upon a chosen spot of it, and tracing on my prepared drawing-paper, (divided in squares of the size required); for instance, when a perforation of 1-10th of an inch is employed, I made my squares on the drawing-paper three inches, by which the perforation, and all that is encompassed within it, is magnified thirty times lineally, and 900 times superficially; and tracing and portraying correctly on my paper the image of the perforation, the drawing will be magnified 30 times linear, and 900 times superficial.

I often wished to improve this silver plate micrometer, by dividing, with some fine silver wires, the orifices into smaller divisions; for instance, the quarter part of an inch might easily be divided into four squares, and the half of an inch into sixteen squares, which would greatly facilitate the operation and the production of correct drawings; but I could never meet with any workman who could execute it properly; but I have no doubt you would soon effect this, or any other improvement of this useful instrument. This apparatus should always accompany a complete microscope.

I have now adopted and practised these methods for more than thirty years, and I do not hesitate to state, that, in my

opinion, they are the simplest, the easiest, and perhaps the best, for producing correct magnified microscopic drawings.

I avail myself of this opportunity to acknowledge and correct an error into which I had inadvertently fallen, when (in the year 1816) illustrating the particles or globules of the human blood: I was then provided with very indifferent optical instruments, and stated the diameter of a globule of the human blood to be 1-1000th part of an inch: but on a subsequent investigation, with a somewhat improved apparatus, I corrected that error, and noted the diameter of these globules to be 1-2000th part of an inch; but having since obtained an improved achromatic microscope, and repeated the measurement with that instrument, can now state with certainty, that each of the globules of the human blood is 1-2500th part of an inch in diameter. I am therefore very anxious to give this explanation, as I perceive that my former erroneous statement is still quoted in some recent publications. In the Penny Cyclopædia, Vol. V. page 4, a table of the size of the globules is given. The author concludes his account of the human blood thus:—

"All observers are agreed that the size of these particles, as long as they retain unimpaired the form they possess on escaping from the blood-vessel, is perfectly uniform; but their real magnitude is variously estimated; the size of the red particle of human blood is, according to

Bauer	1-2000	part of an inch.
Wollaston..........	1-5000	do.
Young	1-6060	do.
Kater..............	1-4000	do.
Prevost and Dumas ..	1-4076	do.
Hodgkin and Lister ..	1-3000	do."

This table proves how difficult it is to ascertain that point; but it also proves, that however erroneous my statement of

1-2000th part of an inch then was, it was nearer the truth than the other measurements.

In hopes that the above will prove satisfactory,

I remain, dear Sir,

Most sincerely yours,

FRANCIS BAUER.

Kew-Green, Nov. 1836.

To Andrew Pritchard, Esq.

EXPLANATION OF PLATE III.

Figure 1.—A, B, C, D, E, are magnified outlines of Fossil Infusoria, composing Tripoli, which has lately been discovered at Franzenbad, in Bohemia*. F is the outline of four globules or sporules of the fungus *Uredo fœtida,* which produce the disease in wheat, called smut-balls or pepper-brand; and G represents globules of human blood. All the drawings in fig. 1 are magnified 400 times linear, or 160,000 times superficial, so that the real dimensions of the above bodies are easily obtained by a direct measurement of their outline in the drawing.

Figure 2.—A represents the outline of a grain of pollen of the *Passiflora quadrangularis;* and B, a grain of the *Œnothera Lindleyana.* The objects in this figure are magnified 200 times linear, or 40,000 times superficial: that is, each square space represents 1-40000th part of a square inch.

Figure 3.—A is a capsule of fern, *Aspidium trifoliatum;* and B the same, burst open, with its sporules or seed thrown out. These objects are magnified 100 times linear, or 10,000 times superficial.

Figure 4 represents the silver plates, with apertures of different sizes.

* These remains of the Infusoria are the silicious shells of animalcules. Some genera exhibit series of delicate transverse markings: they are best seen as transparent objects, in spirits of wine or Canada balsam. They belong to the division Bacillaria.—See my Natural History of Animalcules, page 59; also § 71 (94), 85, 89, &c.—A. P.

No. 2.

ON

A NEW METHOD OF ILLUMINATING MICROSCOPIC OBJECTS.

By the Rev. J. B. READE, M.A. of Caius College, Cambridge.

In Dr. Goring's valuable Memoir on the Verification of Microscopic Phenomena, it is observed, that "the verification of the real nature, form, and construction, of a vast variety of objects which elude the sense of touch by their extreme minuteness, can only be made out by an attentive study of their appearances, *under a variety of methods of illumination**." The methods of illumination at present adopted are four in number, and consist in the application of *direct* and *oblique reflected light*, and *direct* and *oblique transmitted light*.

The first two methods are applicable to opaque objects, but for the examination of transparent objects all the methods are available. The two latter, however, it is well known, are those most commonly used.

Now, when microscopic objects, not opaque, are viewed with oblique reflected light—the flame of the candle being placed higher than the stage of the instrument, and its light condensed upon the object—it is invariably found that the

* Microscopic Cabinet, p. 183, § 16.

maximum of condensed light which can be obtained by this method is insufficient for the full development of many important characters. If, again, transmitted light, either direct or oblique, be substituted for reflected light, obstacles of a still more serious nature greatly interfere with accurate investigation. Delicate tints are lost; colours naturally bright, or even brilliant, are all but absorbed; the texture and construction of objects are erroneously represented; and, in fact, nothing is seen, in many cases, but a magnified image of the object in mere black and white. Nor is this all; for besides this defective representation, the eye of the observer is always subject to much painful excitement, arising from the *intense illumination of the whole field of view.* And here, in fact, lies the great practical inconvenience of the present method; for, to take a common case—an object about 1-300th of an inch in diameter being placed in the middle of the field of view, the diameter of which is about 1-12th of an inch, and consequently being 1-625th part of the area of the field of view, the eye has to contend with 624 parts of bright light, which are not brought to bear upon the illumination of the object. Hence, a method by which this intense glare shall be wholly removed, and that without the loss of a single effective ray, must evidently be superior to the one usually employed, in the ratio of at least 600 to 1.

Being lately engaged in the examination of a few *test objects,* I happened to notice that the feathers of the *Lycæna argus,* when held above the flame of a candle, exhibited at a certain angle all their peculiar tints, and at the same time the flame was not visible to the eye. It then occurred to me, that by preserving the same angle under the microscope, the advantages of amplification would also be accompanied by the natural colours of the object. The requisite angle was readily obtained by making the axis of the microscope coincide with the line from the object to the eye, while the candle and the object retained

their relative positions. The result accorded with my anticipation, and I was gratified by the exhibition of the most brilliant diamond tints, sparkling with exquisite lustre *on a jet-black ground.* This new method of illuminating microscopic objects, it is at once apparent, consists in obtaining *oblique refracted light.*

On submitting a series of objects to the same illumination, I was soon convinced of the value of the discovery; and I scarcely know which to admire most—whether the very natural appearances of objects, adorned, as they invariably are, by the presence of their most delicate colouring, or the personal comfort of the observer, arising from the absence of all superfluous light. To illustrate the two methods by a reference to the telescope, it may be observed, that the discomfort of viewing spots on the sun not unaptly corresponds with the view of miscroscopic objects on an illuminated field; while the removal of all inconvenient and ineffective light from the field of the miscroscope corresponds with the clear and quiet view of stars on the dark blue vault of the firmament.

The most practicable mode of obtaining the illumination now described is to fix the object on the stage of the miscroscope, in the usual way, the axis of which must be inclined to the table, at about an angle of 45°, and then to place the candle about two inches below the stage, and about one or two inches to the right or left of it; but this lateral distance must be varied, according to the nature of the object and the angle of aperture of the instrument. It must be carefully borne in mind that the illumination will not be correct unless the field of view be *wholly darkened.*

To obtain this kind of illumination with facility and effect, it will be necessary to make some alterations in the construction of the instrument: as, for instance, in order to apply condensed light, the arm of the condenser must be placed in a ball-and-socket joint, or some similar contrivance must be adopted; for when it is

perpendicular to the axis of the microscope, its introduction diverts the course of the rays from the candle to the stage, and not unfrequently illuminates the field of view. The mirror also cannot be made available in its present position, for this kind of illumination, because light, when reflected from it, must of necessity illuminate the field. It must therefore be fixed on an extended and jointed arm; and when so constructed, microscopic objects may be viewed even in the daytime by oblique refracted light. Again, a very remarkable microscopic effect will be produced by giving a small vertical angular motion either to the body of the instrument or to the stage, as in Goring's Engiscope*. By this means, the plane of the object which, owing to the present construction, is of necessity parallel to the diameter of the object-glass, may be inclined to it at different angles; and we shall thus obtain *oblique vision* as well as *oblique illumination.* These two conditions are absolutely necessary for obtaining, in many instances, the true effect of coloured objects even with the naked eye, and the introduction of magnifying powers between the object and the eye does not render these two conditions a whit the less necessary.

The effect of this new method of illumination may be tried with advantage on various subjects of the larger kind, as cuttings of wood, scales of fish, and wings of insects†. We may also apply it, with peculiar interest, to the investigation of the elementary organs of plants; animal tissues; mosses; corallines; crystals; and the scales of insects of the orders Lepidoptera and Thysanura. In each and all of these some striking and hitherto unperceived character will be developed, and the observer will rise from his pursuit with a more thorough

* See Microscopic Illustrations, page 39, fig. 1 and 9.

† Among the various objects which shew the superiority of this kind of illumination over transmitted light, the spiral vessels of the hyacinth and the pollen of the convolvolus major are the most decided.—A. P.

persuasion that the Being whose word is power, and by whom his own body "is fearfully and wonderfully made," has equally exhibited the matchless efforts of his skill in the exquisite polish of an insect's joints; in the opening of a leaf; and the pencilling of a flower.—To be a theoretical atheist is impossible.

Peckham, Nov. 1836.

THE END.

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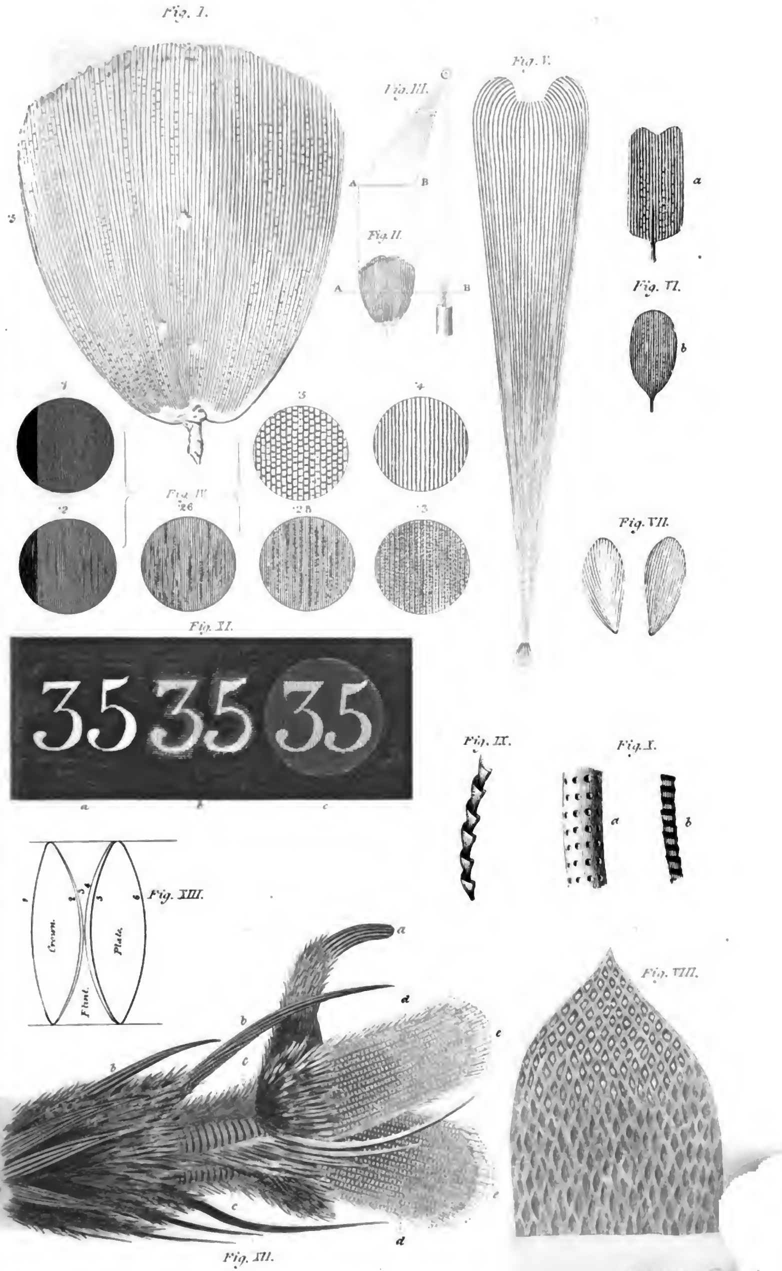

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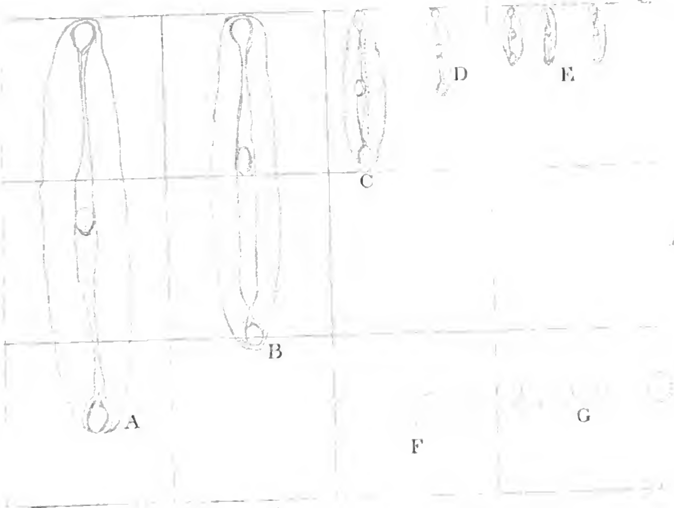


Fig. 1.

Fig. 2.

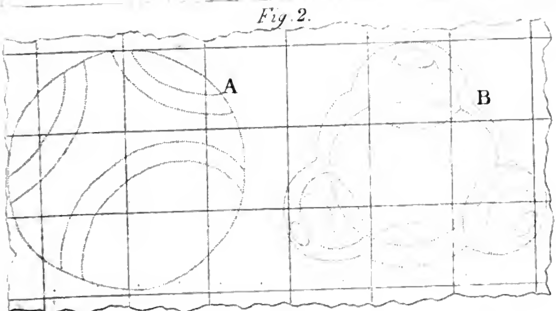
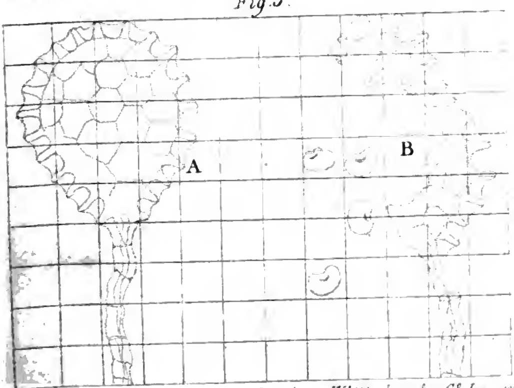


Fig. 3.



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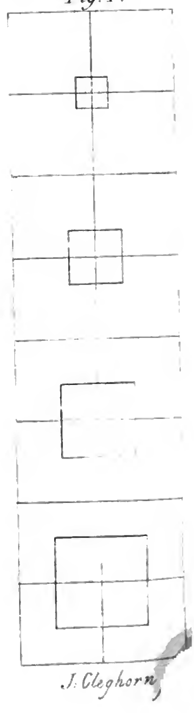

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